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Flight Phase Status Monitor Study

Phase II: Operational Simulation

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Final Report, Phase II

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6. Abstract

This report covers Phase II of a study conducted for the FAA to develop flight status monitor (FSM) concepts. Previous studies of crew alerting systemssuggested the concept of a system which could monitor a flight, alert the crew to non-normal operation and system conditions, guide the crew through the appropriate response procedures and provide feedback to the crew concerning their actions.

The major Phase II activities reported include:

1. Reviewing the results of Phase I and developing a test plan to evaluate the FSM system.
2. Using the results of Phase I to refine the FSM system specifications
3. Finalizing the implementations of the FS simulator hardware and software.
4. Conducting evaluations of the system with experienced transport pilots.
5. Drawing conclusions and working recommendations concerning an FSM system by using the data developed in the evaluation.
6. Identifying issues which used further investigation.

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PREFACE

This study is sponsored by the Federal Aviation Administration and is directed toward the improvement of flight crew performance through the development of standardized aircraft alerting systems for crew alerting and monitoring of flight status. Previous studies suggested that a flight status monitor (FSM) could monitor flight status for abnormal operations as well as aircraft system failures and could guide the crew through the appropriate procedures for the situation. The objective of this study is to develop and evaluate FSM concepts.

This report covers the design, test, and evaluation of flight status monitor concepts conducted under FAA Contract DTFA01-83-C-20033, "Flight Phase Status Monitor Study". The report summarizes both Phase I and Phase II efforts. Phase I developed and made preliminary evaluations of FSM concepts. Phase II consisted of refining and evaluating the relative effectiveness of several candidate concepts.

The authors wish to express their appreciation for the assistance received from their respective organizations. The assistance and guidance of Wayne D. Smith, the Program Manager and Manager of Boeing Flight Deck Research, was of great value. The contract sponsor is the Federal Aviation Administration, and technical guidance was provided by William F. Petruzel, and William F. White, APM-430, the Contract Monitors.

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1.0 INTRODUCTION

1.1 Background

The study of aircraft alerting systems and flight status monitor concepts was initiated in 1973 when the Federal Aviation Administration (FAA) contracted with Boeing to study independent altitude monitors. Follow-on studies conducted during 1974 through 1977 investigated operational philosophies for implementing effective and reliable alerting systems. Study results indicated that there had been a significant increase in the number of alerting signals used on newer commercial transports and very little standardization had been used by the airframe manufacturers in implementing alerting system elements. Table 1.1-1 summarizes the major activities accomplished during these studies.

The identification of these problems led to the Aircraft Alerting Systems Standardization Study contract. The contract was performed as a team effort by the Boeing, Lockheed and McDonnell Douglas aircraft companies. The study was to have been conducted in three phases and culminate with the development of design guidelines for improving and standardizing advanced aircraft alerting systems. During the course of the study contract, however, interest was developed within the FAA in expanding the requirements of the alerting system to monitor flight status and facilitate crew responses to abnormal and emergency situations. A contract modification was made to add a fourth phase to review accident histories and the cockpit environment to determine concept feasibility of a Flight Status Monitor (FSM). Table 1.1-2 lists the major activities conducted under the Aircraft Alerting Systems Standardization Study.

Phase IV study results supported the feasibility of expanding the functions of the alerting system to perform as a flight status monitor. The alerting function of the FSM is identical to that described in the previous studies and that is to alert the crew to all non-normal situations for both flight operations as well as aircraft system operations. However, the functional requirements for the FSM were developed on the assumption that, by providing guidance and feedback information, crew performance could be improved.

TITLE (REPORT NO.)	DEVELOPMENT OF AN INDEPENDENT ALTITUDE MONITOR CONCEPT (FAA-RD-73-168)	INDEPENDENT ALTITUDE MONITOR ALERT METHODS AND MODES STUDY (FAA-RD-75-86)	COLLATION AND ANALYSIS OF AIRCRAFT ALERTING SYSTEMS DATA (FAA-RD-76-222)
Objectives	• Identify nature of typical inadvertent terrain impact scenarios • Identify techniques whereby inadvertent terrain impact accidents might be reduced • Identify functional elements of an independent altitude monitor concept • Identify methods of implementing independent monitor systems	• Develop operational alert philosophy and concepts • Demonstrate and refine selected independent altitude monitor alerting methods • Develop independent altitude monitor implementation plan	• Tabulate current alerting methods, requirements, and functions • Develop method for prioritizing alerting functions • Prioritize alerting functions • Correlate requirements with prioritized functions and note conflicts • Broaden stimuli response data base • Define tests for acquiring stimuli response data not available in literature but required for designing alerting systems • Provide recommendations for standardization of alerting functions and methods
Period	February 1973 to September 1973	June 1974 to July 1975	January 1976 to May 1977

Table 1.1-1. Early Alerting System Studies

TITLE (REPORT NO.)	PHASE I DEFINE PROTOTYPE ALERTING SYSTEM CONCEPTS (FAA-RD-80-68)	PHASE II PLAN TESTS FOR PROTOTYPE ALERTING SYSTEM CONCEPT	PHASE III EVALUATE PROTOTYPE ALERTING SYSTEM CONCEPTS (FAA-RD-81-38 I&II)	PHASE IV ACCIDENT IMPLICATIONS FOR SYSTEM DESIGN (DOT/FAA/RD-82-26)
Objectives	• Acquire missing stimuli response data via appropriate simulator tests • Define alerting system concepts • Assess physical characteristics of each concept • Assess implementation feasibility of each concept • Select alerting system concepts for comparative evaluation	• Select simulation facility • Develop test plan • Coordinate test plan with FAA	• Develop brassboard hardware for selected alerting system concepts • Perform comparative simulator evaluation of selected concepts • Finalize design guidelines for standardized alerting system • Assess certification impact	• Analyze aircraft accident and incident data • Examine the cockpit environment • Develop expanded alerting system design concepts • Identify FSM functional components
Period	January 1979 to November 1979	November 1979 to February 1980	February 1980 to November 1980	July 1981 to June 1982

Table 1.1-2. Aircraft Alerting Systems Standardization Study

Phase IV resulted in the identification of the component functions that can be used to expand an alerting system into a flight status monitor. Specifically, the following additional capabilities are necessary for an alerting system to function as an FSM:

Expanded Sensing - To provide additional sources of status data (e.g., low acceleration, wind shear, tire/wheel failure, navigation).

More Complex Information Processing - To provide additional computational and data handling capabilities and to consider such features as flight phase adaptation, predictive and multiple alerts, alert prioritization, alert inhibition, and integrated checklists.

System Interfacing - To carry out data exchange between the FSM and other data handling systems such as flight management, performance management, flight control, sensor subsystems, navigation, communications and maintenance data recordings.

Displaying - To provide the crew with detailed guidance information to facilitate their response to alerts and provide feedback during and after the response has taken place.

Controlling - To provide the capability for the crew to interact with the FSM.

1.2 Present Study

The objectives of the present study were to develop and evaluate alternate FSM concepts for providing guidance and feedback data to facilitate crew and system effectiveness. Table 1.1-3 summarizes the major activities that were accomplished in the present two-phased contract.

The Phase I effort resulted in the refinement of the FSM concept and the development of several aircraft system display and control concepts to interact with the FSM. Phase I also identified several design and implementation issues (e.g., display formatting, coding schemes, control procedures). During Phase II, experienced transport pilots flew simulated scenarios during which

TITLE	PHASE I DEVELOP PRELIMINARY FSM CONCEPTS (DOT/FAA/PM-84/18)	PHASE II EVALUATE ALTERNATIVE FSM CONCEPTS (DOT/FAA/PM-85/34)
Objectives	● Review revelant data bases to identify FSM functional requirements ● Develop preliminary concepts ● Identify implementation issues ● Define demonstration scenarios ● Implement concepts and scenarios in a flight deck simulator ● Conduct preliminary concept demonstrations ● Refine concepts for Phase II evaluation	● Develop detailed Phase II test plan ● Develop FSM simulation specifications ● Finalize simulator hardware and software designs ● Conduct concept evaluations ● Analyze test results and summarize findings ● Develop conclusions and recommendations
Period		

Table 1.1-3. Flight Phase Status Monitor Study

they operated the aircraft system control concepts in response to alerting situations. A combination of objective (e.g., time, errors, sequence of actions, etc.) and subjective measures (rating scales, debriefing questionnaires and pilot interviews) were obtained. These data provided information for evaluating the flight status monitor and for deriving answers to the implementation issues.

1.3 Report Organization

Section 2 of this report provides an executive summary for this contract. Section 3 provides detailed descriptions of the Phase II activities. In Section 4 the results of the Phase II evaluations are described. Sections 5 contains discussions of the Phase II test results and provides conclusions. Section 6 contains recommendations for future activities. Appendix A provides a detailed description of the test facility. Appendix B contains the training manual that was used to prepare the test subjects for the Phase II evaluation. Appendices C and D contain the concept-evaluation and debrief questionnaires.

2.0 FSM EXECUTIVE SUMMARY

This section summarizes the major activities that were accomplished during Phases I and II of the present contract.

2.1 Phase I Summary

The objectives of Phase I were to: develop preliminary FSM concepts, identify design issues that impact their implementation and develop demonstration scenarios to refine the preliminary concepts.

2.1.1 FSM Functional Requirements

To identify the functional requirements for an FSM the following tasks were performed:

1. Reviewed and refined the results of Phase IV of the Aircraft Alerting Systems Standardization Study.

2. Reviewed current commercial transport aircraft procedural manuals (e.g., TWA 767, Eastern L-1011 and Air Alaska MD-80 Flight Handbooks).

3. Performed a literature review.

   Based on the results of these activities, the following was determined to be needed to satisfy the FSM information requirements:

- Procedures - Step-by-step list of actions required to resolve the alerting situation. These are currently provided by a combination of crew memory items and procedures contained on checklist cards and amplified in flight manuals.

- System Configuration - Representations of the operation and function of aircraft subsystems (e.g., hydraulic, electric). This information is currently either remembered by the pilot or described in flight manuals.

- Failed-System Status - Representations of the faulted subsystems with indications of the failed components. This information is presently contained on systems panels.

- Aircraft Status - Representations of the impact of faulted systems on the operational limits and aircraft flying qualities. This information is either described in flight manuals or remembered by the crew.

- Other Relevent Information - Information pertaining to the alerting situation which is relevant to the remainder of the flight (e.g., plan for a 20° flap landing). This information is currently contained in checklist cards and flight manuals.

2.1.2 FSM and Aircraft System Display/Control Concepts

After identifying these information requirements the study team identified the FSM components and alternative system control concepts. The study team proposed that the above information could effectively be presented on two multifunction color displays:

1. Procedures Display - To provide step-by-step procedural action items to guide the crew in responding to abnormal and emergency conditions.

2. Status Display - To provide aircraft status (including the impact of faults on aircraft operating conditions, limits and flying qualities), system status, and other pertinent information.

Table 2.1.2-1 presents a summary of the candidate aircraft system control concepts. Manual, system aided and automated concepts were developed. For each concept the pilot acquires step-by-step information for resolving the alerting situation from a procedural checklist. For the basic, touch panel, and voice interactive concepts, this information is provided on a multifunction CRT. For the Multifunction Keyboard (MFK) and automated response concepts the procedural information is presented on the MFK scratch pad. Figure 2.1.2-1 shows the locations for the procedures and status displays and the MFK.

LEVEL OF AUTOMATION	CANDIDATE CONCEPTS	CONTROL AND DISPLAY SUMMARY								
		System panel	Procedures display	Status display	Procedures callup automatic	Status callup automatic	Touch panel	Voice	Keyboard scratch pad	Automatic reconfiguration
MANUAL	Basic	X	X	X						
	Basic (with auto display callup)	X	X	X	X	X				
SYSTEM AIDED	Touch panel interactive display		X	X	X	X	X			
	Voice interactive display		X	X	X	X		X		
	Multifunction keyboard			X	X	X			X	
AUTOMATIC	Automated response			X	X	X			X	X

Table 2.1.2-1. Candidate Aircraft System Control Concepts

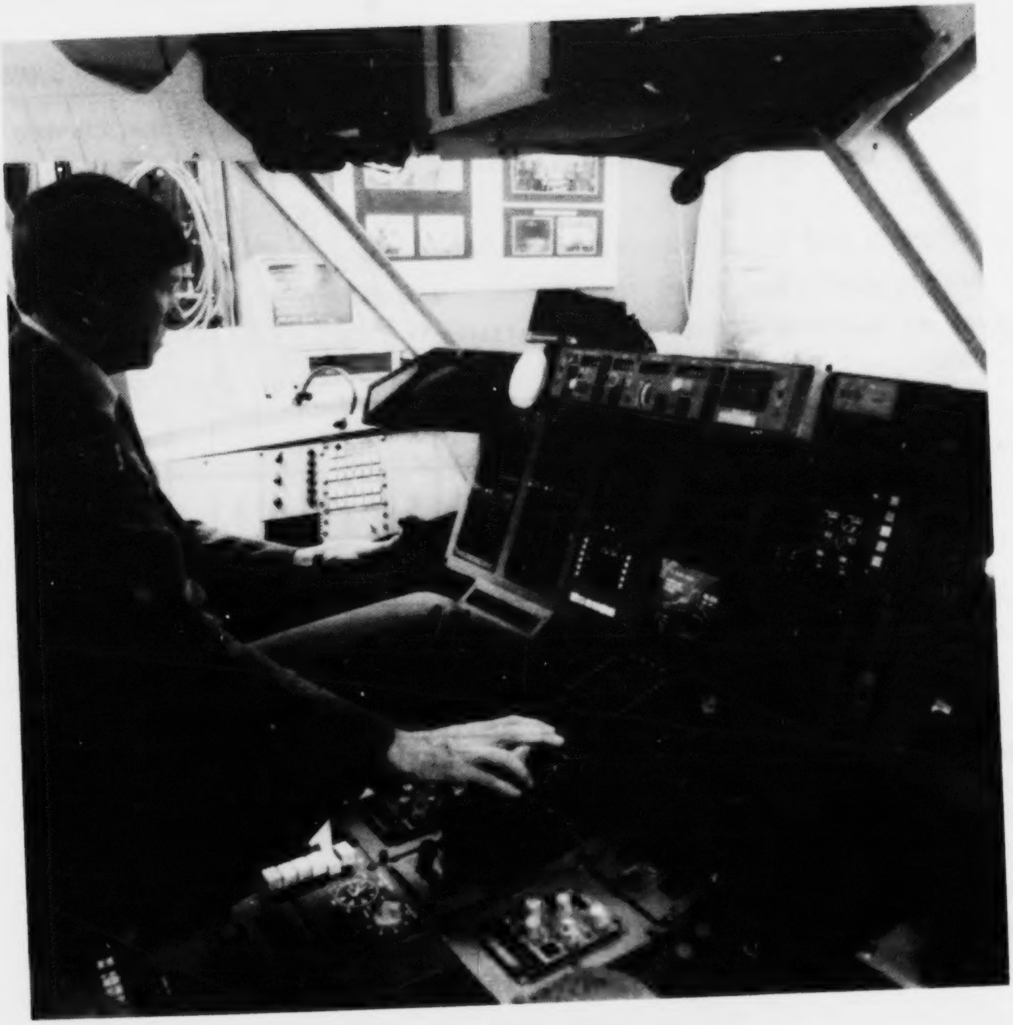


Figure 2.1.2-1. Flight Status Monitor Displays

The major differences between the concepts, therefore, were in the mechanisms provided to enable the crew to perform the procedural action items and the manner in which information was presented to the crew.

Basic - In this concept the pilot used current technology system panels, located on the center pedestal or in the overhead to accomplish the checklist items.

Touch Panel - Here the pilot accomplished the checklist by depressing the appropriate switch, valve, etc., that was represented schematically on the status display. Distinct schematic diagrams were presented for each checklist item.

Voice Interactive - In this concept the pilot depressed the voice switch on the center stick to activate the voice system, and then used voice commands to call up various checklists, status displays and to perform checklist items displayed on the procedural display.

Multifunction Keyboard - Checklist items presented on the MFK scratchpad were accomplished by depressing a switch on the MFK. A single switch, labeled "GO", was used to execute each checklist item.

Automatic Reconfiguration - Implementation of this concept was similar to the MFK concept, except a single switch, labelled "EXEC" was used to initiate the automatic, serial accomplishment of all applicable checklist items. Switches were also provided to stop and restart automatic reconfiguration.

2.1.3 Implementation Issues

During concept development, numerous design issues were identified which required research and evaluation. These issues related to the display content, methods of information coding, and symbology design for the procedures and status displays. Other issues involved mechanisms for crew interaction with the displays, for accomplishing checklist items, and for accomplishing alert prioritization, inhibition and flight phase adaptation.

To provide answers to these design issues a literature review was performed, a questionnaire was developed, and a Phase II preliminary evaluation of alternative concepts were performed. The results of these activities were used to refine the concepts for the Phase II evaluation.

2.1.4 Demonstration Scenarios

The criteria used to develop the scenarios included:

- The scenarios were designed to represent real-world situations which were developed from earlier accident surveys.

- The scenarios were developed to impose realistic pilot task loadings to facilitate the collection of meaningful data.

- The scenarios had to exercise all of the features of the FSM and provide a basis for evaluating their effectiveness.

Three simulated flight scenarios were developed:

1. Differential Lift - An approach in bad weather with a sequence of events which lead up to differential lift and stall situations.

2. Take-off Abort - A scenario in which aircraft and environmental conditions prevent the aircraft from achieving sufficient acceleration for a safe take-off.

3. Navigation Error - Scenario in which navigation errors and multiple system failures occur. If the pilot does not respond appropriately to lower level alerts (cautions, warnings) the situation will degrade and trigger a time-critical warning (ground proximity).

2.1.5 Concept Implementation

The hardware and software required to implement the FSM concepts and demonstration scenarios were incorporated into Boeing's Commercial Airplane Company mock-up and integration laboratory. The center of the facility is a generic widebody flight station cab. The lab, shown in Figure 2.1.5-1 is equipped with state-of-the-art color displays that are used to present flight (HSI, VSI, altitude airspeed, etc.), system status (hydraulic, engine, electrical, etc.) and FSM (alert, procedural and status) information. In addition, operational flight control systems (center stick, throttles, flaps, speed brakes, etc.) were provided to simulate a two-engine commercial jet transport and add realism to the evaluation environment. A complete description of the test facility can be found in Appendix A.

2.1.6 Phase I Concept Evaluations

Two demonstrations were conducted to evaluate and refine the Phase I FSM concepts. The study team members and the FAA contract monitor participated in the first demonstration, and six Boeing pilots served as the test subjects for the second demonstration. The demonstrations consisted of a test conductor going through the simulated differential lift scenario using the FSM Basic concept. Even though only the Basic concept was implemented, all other control concepts were reviewed. During the demonstrations, participant comments and opinions were solicited to obtain data for refining the candidate concepts.

2.1.7 Refine Candate Concepts

The results of all of the activities summarized above were used to provide answers to some of the FSM implementation issues and to refine the concepts for the more detailed Phase II evaluation.

Detailed descriptions of Phase I activities and results are provided in Summers, Berson, Hanson and Rossi, 1984 (Ref. 5).

2.2 Phase II Summary

The objectives of Phase II were to implement the FSM and aircraft system control concepts in a simulator and to evaluate their relative effectiveness in facilitating a pilot's response to abnormal and emergency aircraft situations. The major activities accomplished during this phase are summarized below:

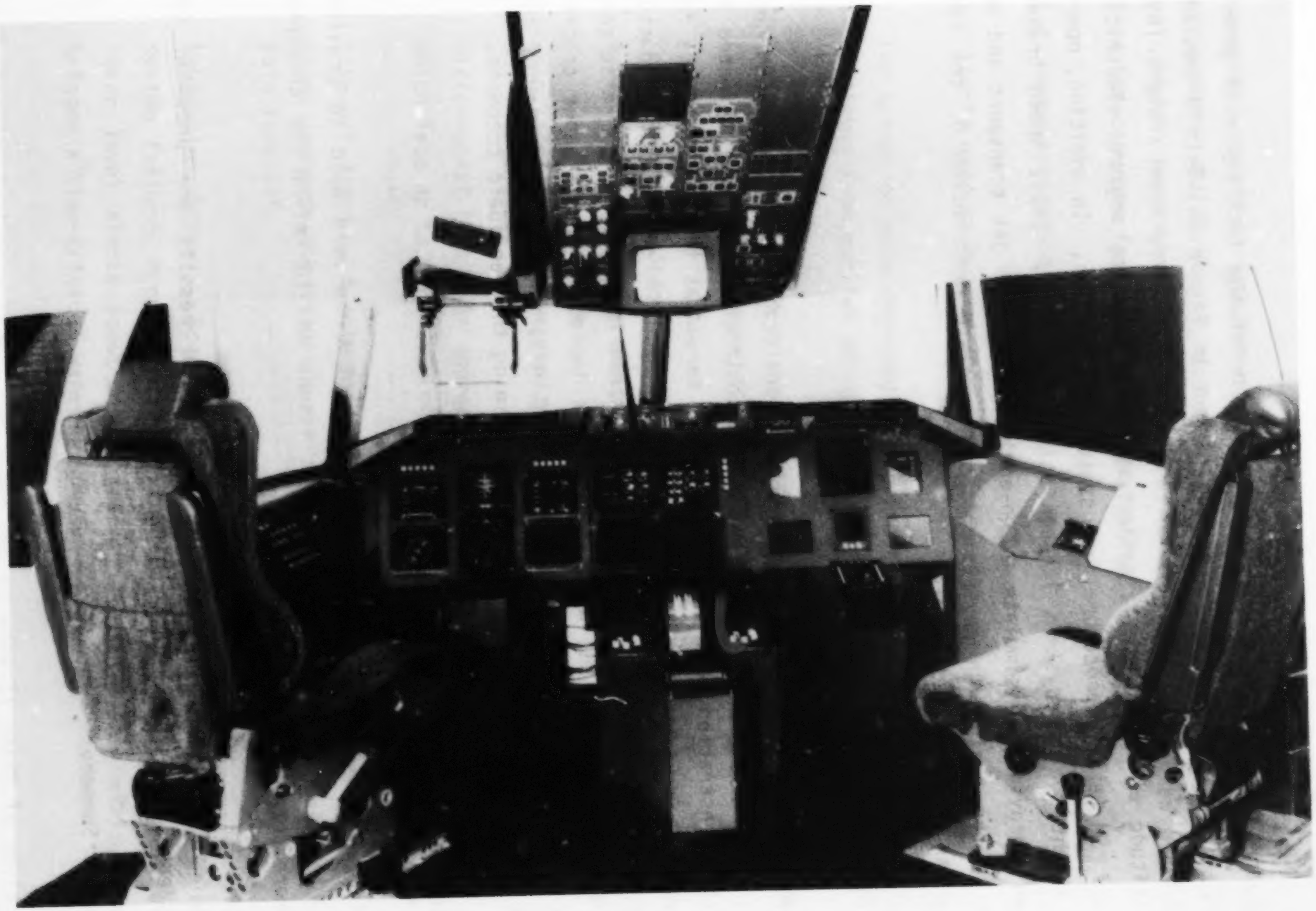


Figure 2.1.5-1. The Research Cab

Develop Phase II Test Plan

led test plan was developed to describe Phase II test objectives and
lities, test subject characteristics, and procedures required to evalu-
preliminary FSM concepts. Two types of evaluation techniques were
r concept evaluation: (1) pilot activity, recorded in real-time and
flight and program debriefings.

t was designed to provide data for evaluating: FSM implementation and
characteristics; the effect of aircraft system control type on the FSM
the relative perceived effectiveness and pilot workload associated
e system controls; and the problems and research issues remaining that
be addressed before developing FSM design guidelines.

Develop FSM Simulation Specifications

jective of this task was to incorporate the changes in FSM functional
s. First the system specification was modified to incorporate the
nal changes derived from the Phase I demonstrations. Appropriate
s recommended by the observers of the concept demonstration were
nted.

y, and more significantly, the concept system to be exercised and eval-
in Phase II was a more complete system than in the Phase I demonstra-
More alerts for a broader range of alerting functions were implemented.
unctions previously handled by the host computer for the Phase I demon-
on were designed into the FSM real-time test configuration.

ition, the test plans and the simulation scenarios were altered to meet
quirements of the Phase II evaluation. Scenarios and equipment were
d as necessary to permit accumulation of pilot performance and prefer-
ata.

2.2.3 Develop Simulator Demonstration Systems

Suitable hardware/software was assembled for the Phase II evaluation in an operational simulator. Hardware subsystems were configured and reprogrammed to perform functions which were not demonstrated in Phase I or were accomplished by the host computer. Necessary interfaces were modified to link the system to the flight simulator.

Prior to installation in the simulator, the system components were bench tested to insure proper operation. This task included testing of subcomponents of the special test equipment as they were reconfigured. Additionally, as more subassemblies and capabilities were added to the test system, operational tests were performed to ensure operability and compatibility. The complete test assembly was bench tested before installation in the simulator.

The test equipment was installed and its operation in the flight simulator was verified including subassembly testing, such as the aural signal generator, the displays, and the data collection/input devices.

Finally, the entire system was pre-tested using the test scenarios, the FSM, and the system control concepts. Prior to conducting the actual test and evaluation, a limited number of sample tests were conducted to assess the reliability of the system and to solidify test procedures and the test schedule.

2.2.4 Phase II Evaluation

Eighteen experienced transport pilots, divided into 10 two-man crews (two pilots flew with an observer pilot as the first officer due to the lack of availability of a second crew member during their test period), served as the test subjects for this study. Each crew flew four training scenarios, four test scenarios, and observed another scenario. In these nine flight segment each crew member either got hands-on experience or observed the execution o the scenarios using each FSM concept.

Prior to testing, the crews were briefed thoroughly and received hands-o experience on the operational characteristics of the simulator, on FS features and on associated test requirements. At the completion of each tes un the crews were required to complete a concept evaluation questionnaire see Appendix C). At the end of the testing each pilot filled out the FSM rogram debriefing questionnaire, contained in Appendix D, and informal nterviews were conducted to solicit additional pilot comments.

2.2.5 Phase II Results

The results section is partitioned into two major sections, one addressing the FSM components and one the aircraft system display and control concepts. The results are summarized below and described completely in Section 4.0.

2.2.5.1 Flight Status Monitor Components

Three FSM display components were evaluated, the alert display, the procedures display and the status display. Pilots also made recommendations concerning the design and implementation of the FSM system.

Alert Display

- Display was well received and considered a necessary part of FSM
- Use was consistent with previous research
- Was used to identify the non-normal condition and its urgency
- Controls associated with the display created some confusion as tested and need to be revised

Procedures Display

- The procedures display was considered an essential element of the FSM
- Use of procedures display was considered much superior to the Quick Reference Handbook
- Both normal and non-normal procedures should be displayed

- Checklist should be displayed automatically for both warnings and cautions
- Checklists for new alerts should be integrated with existing checklist
- Checklist items should be prioritized
- The display should present checklist items and flight critical information
- Full checklist should be available to the crew even if it requires a multiple page presentation
- Feedback indicating completed items was considered essential
- Color coding was the preferred method of providing coded information
- Unnecessary action items should be eliminated

Status Display

- The status display was considered an essential element of the FSM
- Information desired includes aircraft status, failed system status and handbook information
- Aircraft status page should include information about the operational status of the gear, brakes, steering, tires, engines and flight control surfaces
- Aircraft status page should also include operational limitations and restrictions that have been imposed

- Failed system page should present schematics and written text pertaining to the system that has failed

- The failed system page should have the capability of displaying information at different levels of detail according to crew needs

- The checklist status page caused the most concern and its information was not used consistently

- The checklist status page was not considered a desired part of the FSM

Desired Changes

- Reduce the number of button pushes required to operate the system

- Improve the schematics of the status display to make them more easily understood

- Present both warning and caution checklists automatically

- Provide dedicated switches for each status page

2.2.5.2 Aircraft System Control

The methods used to control the aircraft and the types of information available for display by those systems have a significant impact on FSM architecture. Therefore, evaluation data was generated by providing the pilots with experience using the FSM with different control types. This data not only provides an indication of FSM operation, but also furnishes an insight into the type of system controls that could be used in designing the system. Measures of perceived workload and response time were also gathered for each of the control types.

Conventional System Control

- Rated as the most desirable control type because of pilots' familiarity
- Ratings were consistent across all evaluation criteria
- The checklist status page was not used with this type of control
- The checklist status page was considered a distraction

Touch Control

- Requires the checklist status page to operate
- If the checklist status page is required, then it should activate automatically
- Area to be touched should be highlighted
- All switching should be done on the same touch area if possible
- Dedicated system control panels would be required even though the majority of switching is done on the touch panel
- Effectiveness of touch panels was questioned under vibration condition, e.g. turbulance

Voice Control

- The scope of the test and the available training time did not permit an accurate assessment of voice control
- Pilots were frustrated by recognition inconsistency

- The voice control used did not seem appropriate for simple switching functions, which could be as easily accomplished manually

Multifunction Keyboard Control

- It is necessary to decide which items are controlled from the keyboard and which require system controls and to make the distinction clear to the crew

- Monochromatic displays make it difficult to distinguish between completed and uncompleted items and to find the current action item

- Much more positive coding is required for a monochromatic display

Automatic Reconfiguration

- This control concept rated the highest on most of the evaluation criteria

- As with any automatic system, it must have a low probability of failure before it is generally accepted

- Functions that are controlled by the automatic system must be distinguished from pilot functions

- Features considered essential to the automatic system include:

  - Selection of automatic should be a crew option
  - Systems should have the capability of stopping the automatic sequence
  - System should stop before critical items
  - Automatic sequence should stop when a new alert appears
  - Information should be presented which reflect any reconfiguration

The pilots were asked to compare the workload imposed by using the system control concepts that they flew (the automatic concept was only demonstrated) and the FSM as compared to their present system. The interpretation of these results must be made realizing that the operational procedure of requiring the flying pilot to perform the action items imposes a higher workload than normal flight operations. This difference withstanding, the airline pilots consistently rated all the control concepts as easier than their present operation, while certification pilots' average rating of the workload was the same or more difficult than current operation. All the pilots felt that the display of checklists significantly decreased their workload. Color coding the action items decreased the time required to identify the information they wanted and the mental effort required to keep track of the whole response process. Centralization of the information reduced overall scanning and permitted the crew to quickly identify the pertinent information.

The time taken to complete the checklist items was used as a measure of the effectiveness of the FSM/system control system. An analytic number was generated for the automatic reconfiguration concept using 2.5 seconds for system actions (the average time required for this type of action and to display the reconfiguration information) and 10 seconds for pilot response items (an average time from the test data for pilot "check" items). Comparing this figure with the test data the automatic system performed significantly faster than any of the manual or semi-automatic systems, as was expected. For normal procedures the type of system control (not considering automatic) did not seem to have an effect on response times. However, for non-normal situations the amount of automation and the urgency of the alert determined the time taken to respond. This indicates that where time becomes a factor, the crews take advantage of features which reduce the time to respond.

2.2.6 Discussion and Conclusions

The ability of the flight status monitor to provide guidance and feedback along with the alerting functions offers a potential of improving aircraft safety by enhancing the effectiveness of the flight crews in both normal and on-normal situations. It achieves this potential by reducing the probability f error, the time to respond and the perceived workload while making more of he crew's channel capacity available for flying the aircraft.

ecause of its central location and coding of information the alert display as seen as facilitating the pilot response to alerts. The aircraft alerting ystem guidelines established in previous work should be used in designing his display. The controls associated with the alerting components include: a ethod of storing nonwarning alerts; a means of recalling stored alerts; a ethod of paging through the display; and the capability of selecting a pecific alert(s) in order to perform some system actions.

he guidance component is provided by the procedures display, which was preerred over the quick reference handbook as a means of providing checklists. t was identified as a necessary component of the FSM because it not only preented the appropriate action steps, but also kept track of what had been performed. The results indicate that the pilots wanted to use the checklist to plan their course of action and to know which actions had already been accomplished. In order to effectively take advantage of the guidance component the FSM should have the capability to formulate, integrate and modify checklists according to the situation. Checklists should be limited only to the actions that are required. Unnecessary actions should be eliminated. Contingency statements ("IF") that depend on system data should be eliminated. For multiple checklist situations, the system should be able to integrate and prioritize the action items to facilitate the response. Again, the guidance display should follow the alerting system guidelines. The controls associated with this component should provide the capability to: select checklists not only for current problems and for normal procedures associated with the current flight phase, but also for any other normal or non-normal procedure that they wish to review; page the checklist forward and backward; select a different sequence of action based on situational knowledge; and signal the completion of a pilot action.

The major feedback component of the FSM system is the status display. Three pages of information should be used to provide this feedback: the overall aircraft status page; the failed system status page; and the supplemental information page. The requirement for providing information about the action items in the checklists is dependent on the type of aircraft system control being used. If the controls require an interaction with the status display, e.g., touch panel, then a checklist status page is needed. Pilots felt that the aircraft status page should be presented automatically when a non-normal situation requires immediate attention or action. It should also be available at all times for manual activation and be continuously updated. Both alphanumeric and graphic techniques should be used to integrate the appropriate information. The failed system status page presents information concerning the failure and its effect on associated systems and should have the capability of presenting more detailed information on request. Graphic and alphanumeric presentation techniques should be used for this page also. The information page of the status display provides the crew with supplemental information from the flight manual about non-normal situations. As the feedback component of the FSM the status display should have characteristics which are in accordance with the guidelines previously documented.

Control functions associated with the status display should provide the capability to: activate the status display; select the particular status page that is required; page through the sub-pages; and select greater detail on the failed system status page.

During this study the FSM was tested with five different concepts for controlling the aircraft systems. This combination demonstrated that the design of the FSM is affected by the system control concept being employed. Because system control is aircraft-design specific, the FSM must be designed to accommodate a wide range of design concepts. Furthermore, the advanced technologies used to operate the aircraft systems are amenable for FSM system control.

2.3 Recommendations for Future Activity

Two areas of activity are addressed, the FSM/pilot interface and the FSM/aircraft interface. The Phase I and Phase II efforts have identified a number of issues concerning the FSM/pilot interface, which require resolution before any meaningful guideline can be written. One objective of any future program hould be the resolution of these issues in an integrated testing program and he use of the resulting data to update and refine the FSM. The updated FSM hould then be installed in a full mission simulator so that it can be validaed against conventional alerting methods for all levels of alerting activity.

Concerning the FSM/aircraft interface, in order for the FSM to be effective it must be able to gather and process large amounts of information about the ircraft. Traditional computing techniques requiring well structured problems with complete data bases and a single correct solution may not be applicable to the FSM processing. Artificial intelligence on the other hand is a technique which can operate with ill structured problems which require a search for a solution and can use incomplete information to arrive at a probabilistic answer. The most applicable subfield of artificial intelligence to the FSM problem would be the knowledge based expert system. Some of the issues which need investigation to apply this type of computing technique and interface the FSM with the aircraft include:

1) Definition of the scope of the knowledge base
2) Establishment of an expert pool for building the data base and develop a scheme to integrate data from a number of experts and provide a single meaningful answer
3) Identification of the set of alerts
4) Investigation of operational and design considerations with respect to their impact on system sensors and potential FSM operation
5) Definition of prioritization and inhibition schemes for both alerts and checklists and identification of an implementation plan
6) Determination of the impact of arriving at probabilistic answers on the definition of system reliability
7) Development of a plan and criteria for the test and certification of expert systems

3.0 PHASE II TECHNICAL APPROACH

As a result of Phase I, it became evident that limitations in the existing data base precluded answering all FSM design and implementation questions. Phase II of the study added to the data base by evaluating the candidate concepts in a simulated cockpit environment. The FSM was evaluated by having experienced jet transport pilots fly scenarios with the FSM and different system control concepts and respond to a sequence of alerts. A combination of objective and subjective performance measures were used to evaluate the FSM and the alternative display and control concepts. The existing data base was expanded and remaining limitations were identified.

3.1 Objectives

The overall objective of Phase II was to evaluate the design, implementation, and the perceived effectiveness of the FSM and candidate aircraft system control concepts.

The specific objectives were:

1) To determine if the FSM concept increases the pilot awareness of the operational status of the aircraft.

2) To determine what information the pilot uses when responding to non-normal situations and to determine if there are any specific information-gathering patterns associated with the different display and control concepts.

3) To evaluate the capability of each candidate concept to operate in a fixed-based simulated flight deck environment.

4) To determine the perceived workload required to operate the FSM concepts and the effect of system control on that perception.

5) To determine what changes are recommended by the user community for FSM design and implementation.

Statistic	PILOT** EXPERIENCE		SPECIFIC AIRCRAFT EXPERIENCE (NUMBER OF PILOTS)								
	Flight-hours	Years flying	Regency*	707	727	737	747	757/767	DC-9	DC-10	DC-8
Mean	8420	27.2	A		4	1	3	5			
Standard deviation	6117	10.5	B		1	4		3	1	2	2
Range	2660 to 25400	13 to 40	C	1	1	3	1		1		1
			D	2	1		1				

A is the most recent aircraft flown

Table 3.2-1. Summary of Pilot Experience (Data Returned by 13 Pilots)

.2 Subject Pilots

ighteen experienced jet transport pilots participated in the Phase II simulator tests. In order to get an input based on a wide range of experience, pilots were selected from three areas of the flying community: line operations; certification; and manufacturing. Six line pilots representing Alaska, United, and Northwest Orient airlines, six FAA certification pilots from the Northwest Region four engineering test and two training pilots from Boeing made up the sample. As a group, each of the pilots that responded to the debriefing questionnaire (13 pilots responded) averaged 8420 flight hours and 27 years of flight experience. All of the pilots were qualified on more than one aircraft and over half of them were qualified on more than two. A summary of their experience is presented in Table 3.2-1. The numbers on the right hand side of the table indicate the specific experience by aircraft type and the order of that experience (A is the most recent). As can be seen, the sample contains a wide range of aircraft experience from which to respond to the subjective questionnaire.

3.3 Facilities

The nature of the test dictated the use of a facility which could provide a flight deck environment and be flexible enough to accommodate the flight status monitor and various aircraft system display and control concepts. The facility chosen for the evaluation was the Boeing Aircraft Company Flight Deck Research Laboratory. This facility was designed to provide a generic cockpit environment for the test and evaluation of new control and display technologies. The basic functions for which the facility was designed are to evaluate crew information requirements, the display technologies for providing this information and the control technologies for crew interaction.

A second purpose of the facility is to evaluate the integration of new technology into the flight deck. It accomplishes this purpose through the use of modular design which provides the flexibility to permit the easy introduction of new hardware and the ability to change the flight deck system configuration. System software is also modularized to facilitate change. Interface equipment is flexible allowing for a wide variety of engineering development activities. Figures 3.3-1 and 3.3-2 illustrate these facilities and a more detailed description is provided in Appendix A.

In addition to the airplane/flight deck simulation, the FSM simulation system was implemented to represent the FSM information under a variety of normal and non-normal situations. The system consists of six basic elements: (a) the alert controller which was the controlling element for the alerting lights, tone and voice; (b) the scenario controller which controlled the alert scenarios; (c) the FSM logic unit which provided the rules for FSM operation; (d) the graphics generator which provided the checklists and all schematics; (e) the aircraft system display and control components which provided the means to operate the aircraft systems; and (f) the communications network which had the ability to establish two-way communications with the crew and to make both audio and video flight records. A self-contained data recording system was also available for the FSM simulator.

The underlying objective in the development of the FSM simulation system was to provide a flexible tool which could be utilized throughout the FSM program. It is capable of reproducing the flight deck alerting functions in a wide variety of normal and non-normal situations at any time during a flight. It can provide this capability for a wide range of test paradigms that may range from bench testing to high fidelity simulation or possibly flight test. The modular design of the system permits the utilization of new sensor data and new alerts as they become available. Because the scenario controller generates alert sequences, any operational problem can be investigated.

The voice generation model can provide an accurate reproduction of any voice model whether it is commercially available or experimental in nature. The data collection module is a floppy disk based recording and play back system which is not dependent on the host computer. Using the disks that are recorded in real time, the system can play back the sequence of actions that were taken to resolve any situation. A full description of the FSM simulation system is presented in Appendix A.

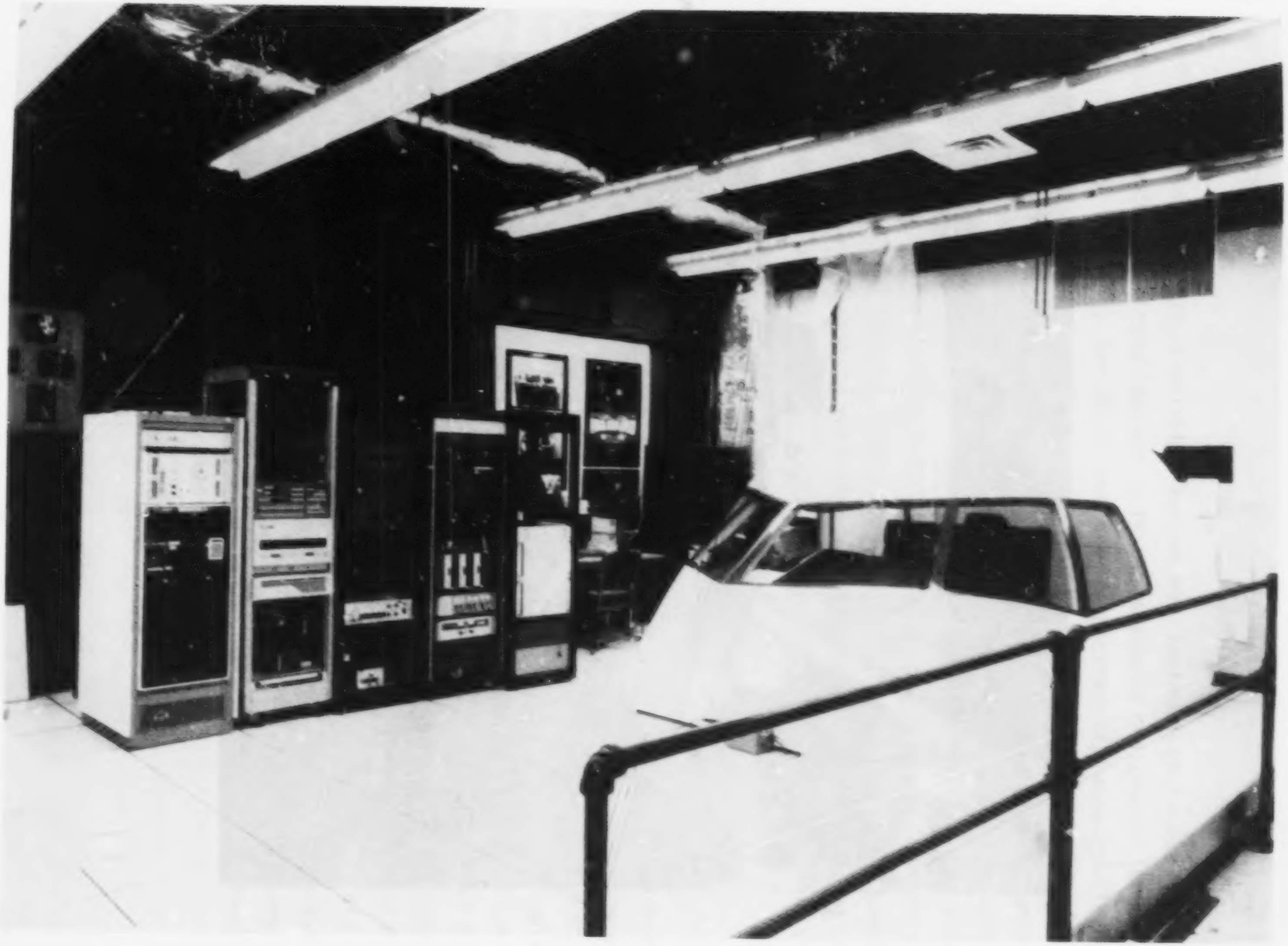


Figure 3.3-1. Mock-up and Integration Laboratory

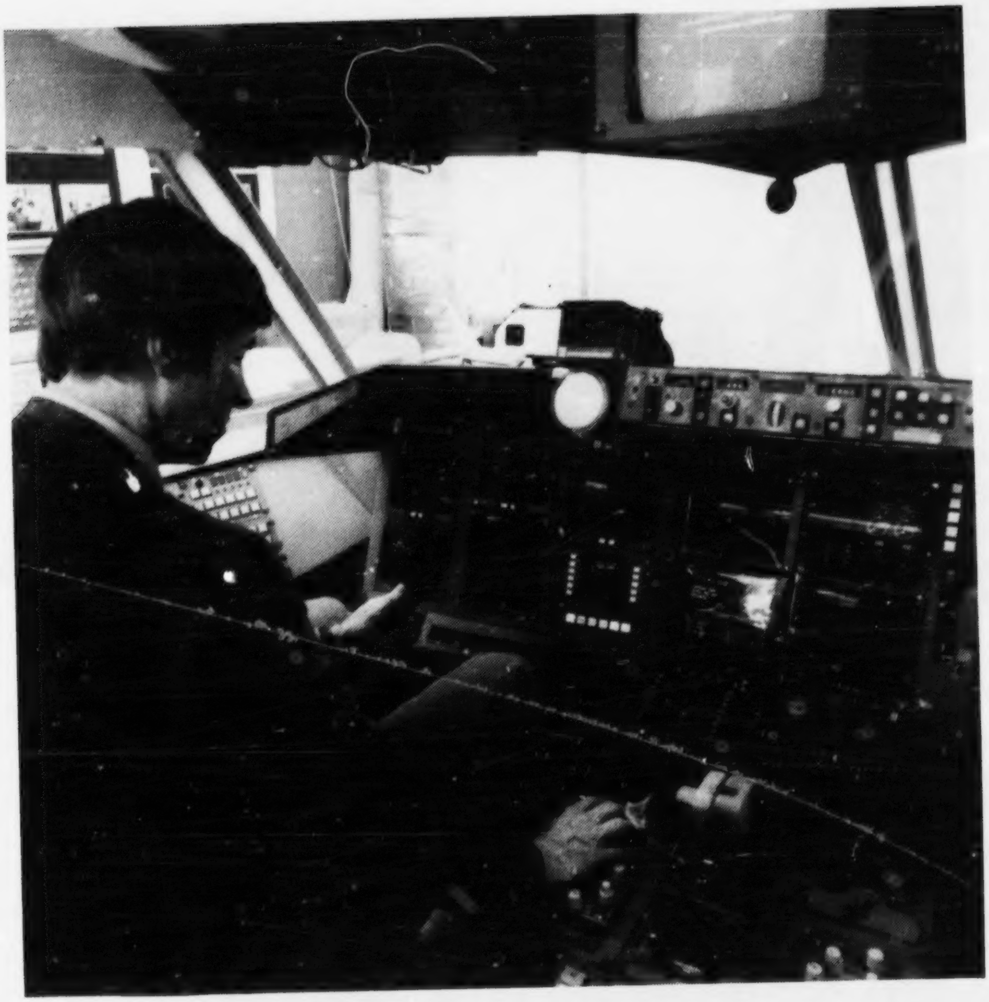


Figure 3.3-2. Advanced Flight Deck

3.4 Methodology

The flight status monitor simulation system was implemented in the test cab. An aircraft model was installed and a flight scenario designed. Three alert scenarios, one training, one test and one demonstration, were developed to exercise the system and the FSM functions. The pilots, in crews of two, flew the scenarios with four system control concepts and observed a demonstration of the fifth. The pilot performance was observed and recorded during the training and test flights. After the completion of each test flight a questionnaire was administered to obtain the pilot's opinions on FSM operation with the system control concept that was just flown. Through these questionnaires the pilots were able to make their inputs concerning the FSM implementation, design and utilization.

3.4.1 Evaluation Rationale

A review of the candidate aircraft system display/control concepts revealed that some of the designs of their prototype implementation were more advanced than others. It was decided by the study team that conducting a comparative evaluation using performance data would be unduly affected by those concepts whose technological development was not as advanced as the others, and the resulting interaction with the FSM operation could mask any effect of the information provided by the system on crew performance. It was therefore concluded that the study would be more meaningful if the operational and procedural aspects of each concept were presented to the pilots and evaluated. This data would permit the investigation of the operational and information management aspects of concepts as well as allowing the pilots to compare the concepts. This conclusion did not compromise the basic intent to refine the concept of flight status monitoring.

3.4.2 Concept Implementation

3.4.2.1 Flight Status Monitor Components

The flight status monitor system consisted of the alerting components which attracted the crew's attention to the non-normal situation, identifying the problem and providing an indication of its urgency; the guidance component which contained the information for the crew to respond to the situation; th feedback components which provided the crew an indication of the aircraf status and indicated what effect the crew response was having; and the contro components which permitted crew/FSM interaction.

The alerting components were comprised of master visual and aural alerts ar the alert display. The master visual alert was located on the glareshield ar the master aural alert consisted of a different sound for each of the thre urgency levels. Both of these alerts could be cancelled by depressing th master warning/caution switch. Simultaneously with the master alert, an alpha numeric message appeared on the alert display. The alerts were color code and prioritized according to alert level and time of occurrence. In additio there was a voice display that occurred automatically for a time-critica alert and was selectable for the remainder of the alerts by depressing th thumb switch on the control stick.

The guidance and feedback components were provided by two displays: the pro cedures display and the status display. The procedures display presente step-by-step procedures in a checklist format with one action per line. Th lines were color coded to differentiate the completed and the incompleted pro cedures. The status display had four major pages of information providin pictorial and alphanumeric presentations of:

1) The aircraft status showing the operational limits and the nonoper ating systems.

2) Simplified schematic diagrams of the systems involved in the proce dural items.

3) A simple schematic diagram identifying the primary failure.

4) Additional information affecting aircraft operation.

The FSM is operated by using the line select and function control keys. Th line select keys allow the selection of a specific alert. The keys at th bottom of the display allow selection of the procedures and status displays, alert display paging, storage and recall of alerts and voice control activation.

Figure 3.3-2 presents the FSM layout in the simulator. The alert display was located on the lower right side of the pilot's panel; the procedures display is the upper left display in the center panel; the status display is directly under the procedures display; in the upper left corner of the center isle stand is the multifunction control-display unit (CDU) which for one of the test flights was used to present a monochromatic version of the procedures display.

3.4.2.2 Aircraft System Interaction Concepts

The FSM was tested using a number of different means of interacting with the aircraft systems, including: the system control panels; the touch control panel; a voice interactive control panel; and a multifunction keyboard. Detailed descriptions of these different components and the different concepts are presented in Appendix B. A summary is presented in the following paragraphs:

Basic Concept - The operation of the basic control concept is presented in Figure 3.4.2-1. After cancellation of the master alert by means of the master caution/warning switch, the procedures and status displays were called up automatically for warnings and by using the line select function for alerts of a lower urgency. The crew performed the necessary actions on the systems control panels located either in the overhead panel or the central pedestal. After completion of the checklist procedures, checklist and status displays were cleared, and the message was removed from the alert display, if the alerting situation no longer exists. If the alerting situation remained, cautions and advisory alerts could be cleared from the alert display by selecting the store key.

Touch Panel Interactive Concept - This concept is illustrated in Figure 3.4.2-2. In this concept the procedures and status displays were also called up automatically for warnings or when the crew selected the line select key

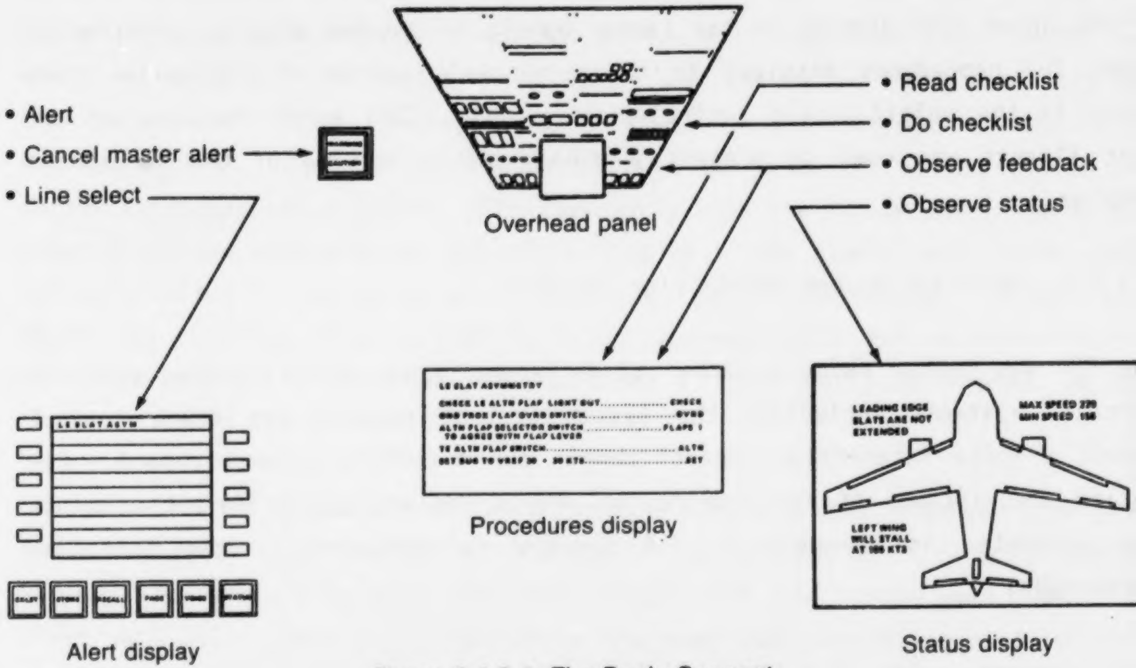

• Alert
• Cancel master alert
• Line select
• Read checklist
• Do checklist
• Observe feedback
• Observe status
Overhead panel
LE SLAT ASYM
Alert display
LE SLAT ASYMMETRY
CHECK LE ALTN FLAP LIGHT OUT.................CHECK
GND PROX FLAP OVRD SWITCH.....................OVRD
ALTN FLAP SELECTOR SWITCH ....FLAPS 1
TO AGREE WITH FLAP LEVER
TE ALTN FLAP SWITCH..............................ALTN
SET BUG TO VREF 30 + 30 KTS.....................SET
Procedures display
LEADING EDGE SLATS ARE NOT EXTENDED
MAX SPEED 270
MIN SPEED 156
LEFT WING WILL STALL AT 186 KTS
Status display

Figure 3.4.2-1. The Basic Concept

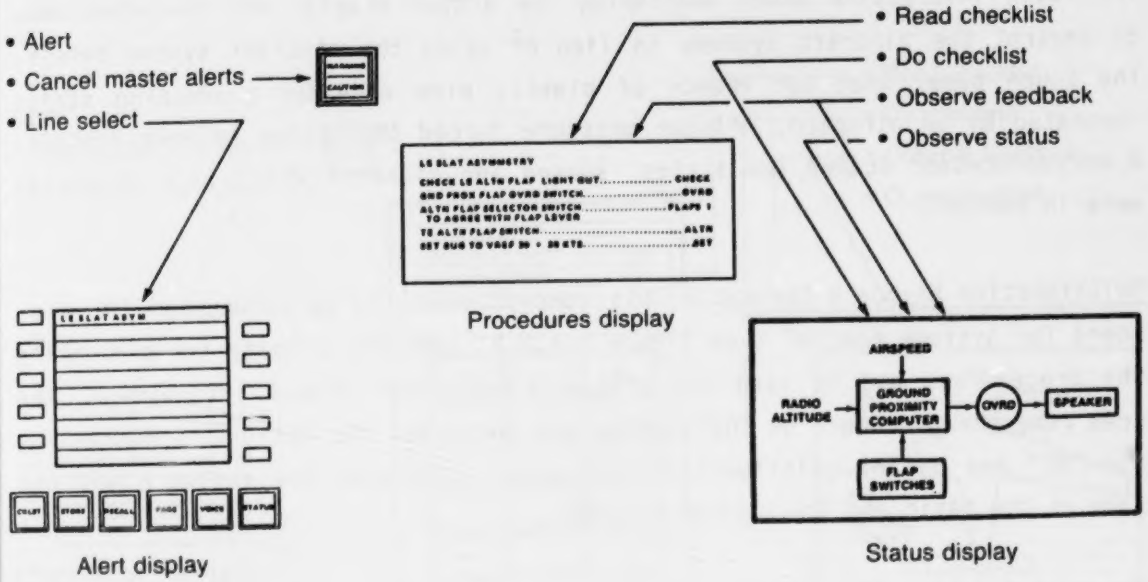

• Alert
• Cancel master alerts
• Line select
WARNING
CAUTION
LE SLAT ASYM
CLEAR
STORE
RECALL
PROC
VOICE
STATUS
Alert display
• Read checklist
• Do checklist
• Observe feedback
• Observe status
LE SLAT ASYMMETRY
CHECK LE ALTN FLAP LIGHT OUT.................CHECK
GND PROX FLAP OVRD SWITCH.....................OVRD
ALTN FLAP SELECTOR SWITCH....................FLAPS 1
TO AGREE WITH FLAP LEVER
TE ALTN FLAP SWITCH..................................ALTN
SET BUG TO VREF 30 + 20 KTS.......................SET
Procedures display
AIRSPEED
RADIO ALTITUDE
GROUND PROXIMITY COMPUTER
OVRD
SPEAKER
FLAP SWITCHES
Status display

Figure 3.4.2-2. The Touch Panel Interactive Display Concept

for the lower urgency alerts. The crew performed the necessary actions on t status display using a touch panel overlaying a schematic diagram of t systems involved. Feedback information was presented on both the procedu and status displays.

The touch interactive panel overlaying the status display was therefore us to control the aircraft systems in lieu of using the aircraft system panel The touch panel used two sheets of plastic with embedded conducting stri separated by an airspace. Finger pressure forced the strips to make contac A microprocessor scaned the strips, sensed and signaled which pair of stri were in contact.

Multifunction Keyboard Concept - This concept used the multifunction CDU ke board for systems control (see Figure 3.4.2-3), and its display for presenti the procedures, and it used the status display for status information. T crew read the procedure on the display and performed the actions by depressi the "GO" key on the multifunction keyboard. Otherwise the sequence was t same as the basic and touch panel concepts.

The multifunction CDU contains a matrix of 15 multilegend switches and a fl panel display in a control display unit configuration. Each switch has a by 35 dot matrix sunlight readable LED display. The array provides a resol tion of 40 lines per inch and is capable of providing two rows of six 5 by characters. The brightness and refresh rate are under software contr through a logic and refresh control unit.

Voice Interactive Concept - Voice presentation was used for alert messages a for this concept voice was selected to control the FSM displays and the ai craft systems (see Figure 3.4.2-4). As a back-up, both displays and syste could be manually controlled as described earlier. By selecting the voice k on the alert display, the voice system was armed and voice control was act vated by pushing a button on the control stick and saying "voice ready". Th crew executed an action by depressing the button again and saying "GO". Fee back was presented on the procedures and status displays. A Texas Instrument Command System was used for voice control. This system combines speec synthesis and recognition into a single unit. The speech synthesis compo

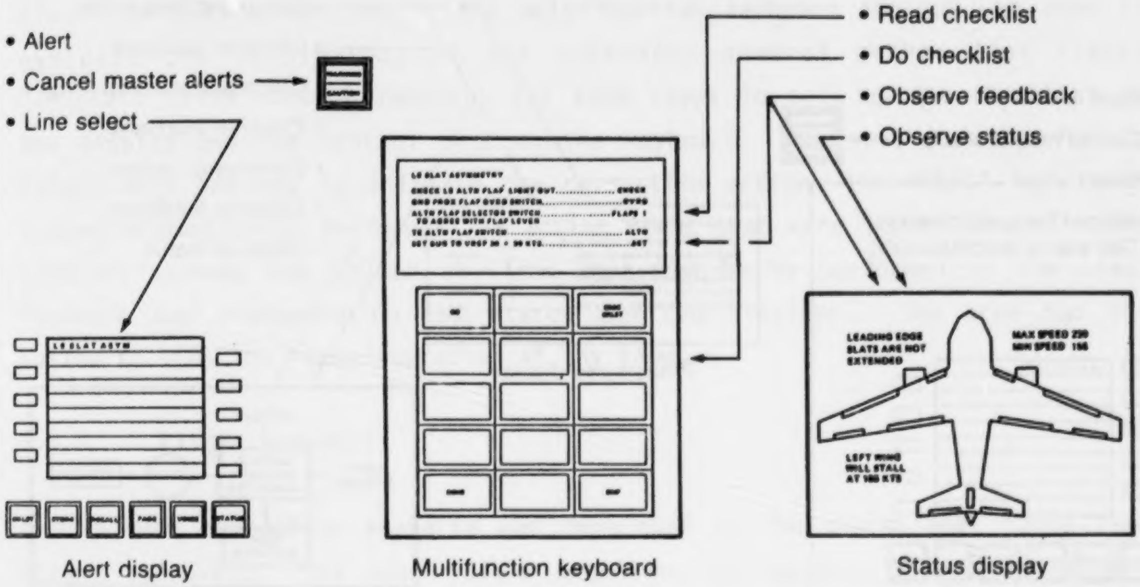

• Alert
• Cancel master alerts
• Line select
• Read checklist
• Do checklist
• Observe feedback
• Observe status
LE SLAT ASYM
LE SLAT ASYMMETRY
CHECK LE ALTN FLAP LIGHT OUT..........CHECK
GND PROX FLAP OVRD SWITCH..........OVRD
ALTN FLAP SELECTOR SWITCH..........FLAPS 1
TO AGREE WITH FLAP LEVER
TE ALTN FLAP SWITCH..........ALTN
SET BUG TO VREF 30 + 30 KTS..........SET
LEADING EDGE SLATS ARE NOT EXTENDED
MAX SPEED 220
MIN SPEED 156
LEFT WING WILL STALL AT 160 KTS
Alert display
Multifunction keyboard
Status display

Figure 3.4.2-3. The Multifunction Keyboard Concept

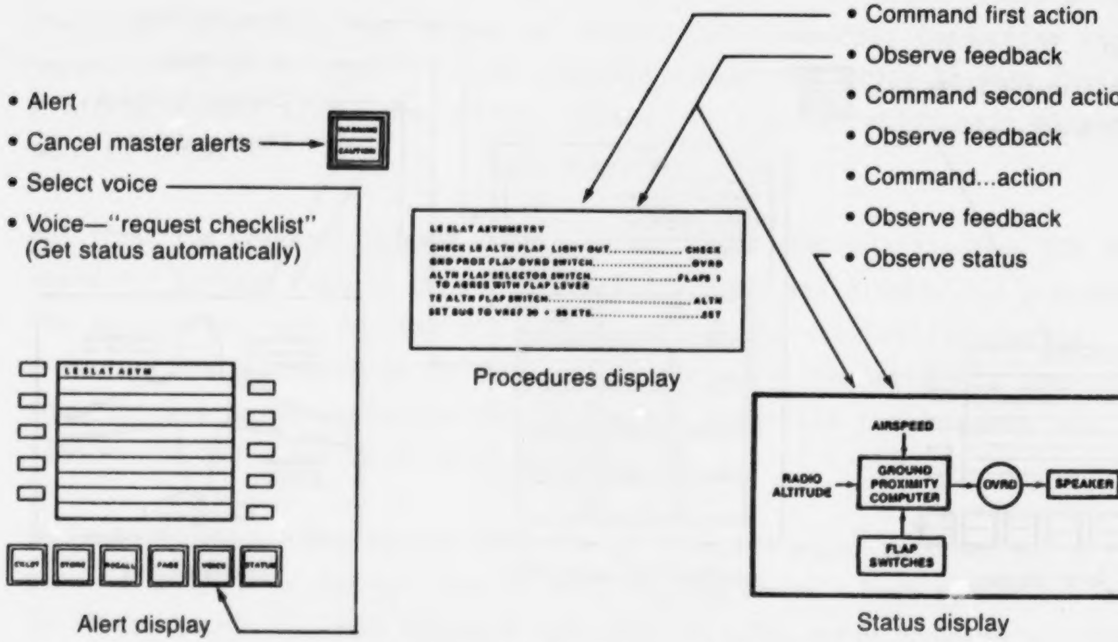

• Alert
• Cancel master alerts
• Select voice
• Voice—"request checklist" (Get status automatically)
LE SLAT ASYM
RECALL
PAGE
VOICE
STATUS
Alert display
LE SLAT ASYMMETRY
CHECK LE ALTN FLAP LIGHT OUT.................. CHECK
GND PROX FLAP OVRD SWITCH..........................OVRD
ALTN FLAP SELECTOR SWITCH.....................FLAPS 1
TO AGREE WITH FLAP LEVER
TE ALTN FLAP SWITCH.....................................ALTN
SET BUG TO VREF 30 + 20 KTS...........................SET
Procedures display
• Command first action
• Observe feedback
• Command second actio
• Observe feedback
• Command...action
• Observe feedback
• Observe status
AIRSPEED
RADIO ALTITUDE
GROUND PROXIMITY COMPUTER
OVRD
SPEAKER
FLAP SWITCHES
Status display

Figure 3.4.2-4. The Voice Interactive Display Concept

nent uses a linear predictive coding algorithm to model the human voice. The voice recognition component is speaker dependent and must be trained for each user. It recognizes connected streams of words allowing the pilot to use normal sentences to issue commands.

Automatic Reconfiguration Concept - Any of the automated or system aided control concepts could incorporate pilot-initiated automatic system reconfiguration. In the current study, the multifunction keyboard concept was used to evaluate the feasibility of the automatic control method (see Figure 3.4.2-5). This concept requires the same steps to call up the checklist on the display and the control keys on the keyboard. However, the crew had to select only one key to initiate the corrective action, the "EXEC" key. The system automatically performed the action items that were interactive with the aircraft systems and paused at items that had to be performed by the crew. Feedback was presented on the status and CDU displays. The crew had the option to stop the reconfiguration at any time.

3.4.3 Flight Scenario

A 40-minute navigation scenario was developed as the operational route (see Figure 3.4.3-1). The test flight began on the segment after the holding pattern and before the turn toward Paine Airfield and lasted approximately 20 minutes. The pilot used the available minimum of flight instrumentation (see Section 3.4.5) to make a nonprecision instrument approach into Boeing Field.

3.4.4 Alert Scenarios

The three alert scenarios (i.e., differential lift; navigation error; and rejected takeoff) described below were developed to evaluate the FSM and system display and control concepts.

The differential lift scenario was used as the test scenario while the navigation error scenario was used for training and the rejected takeoff as a

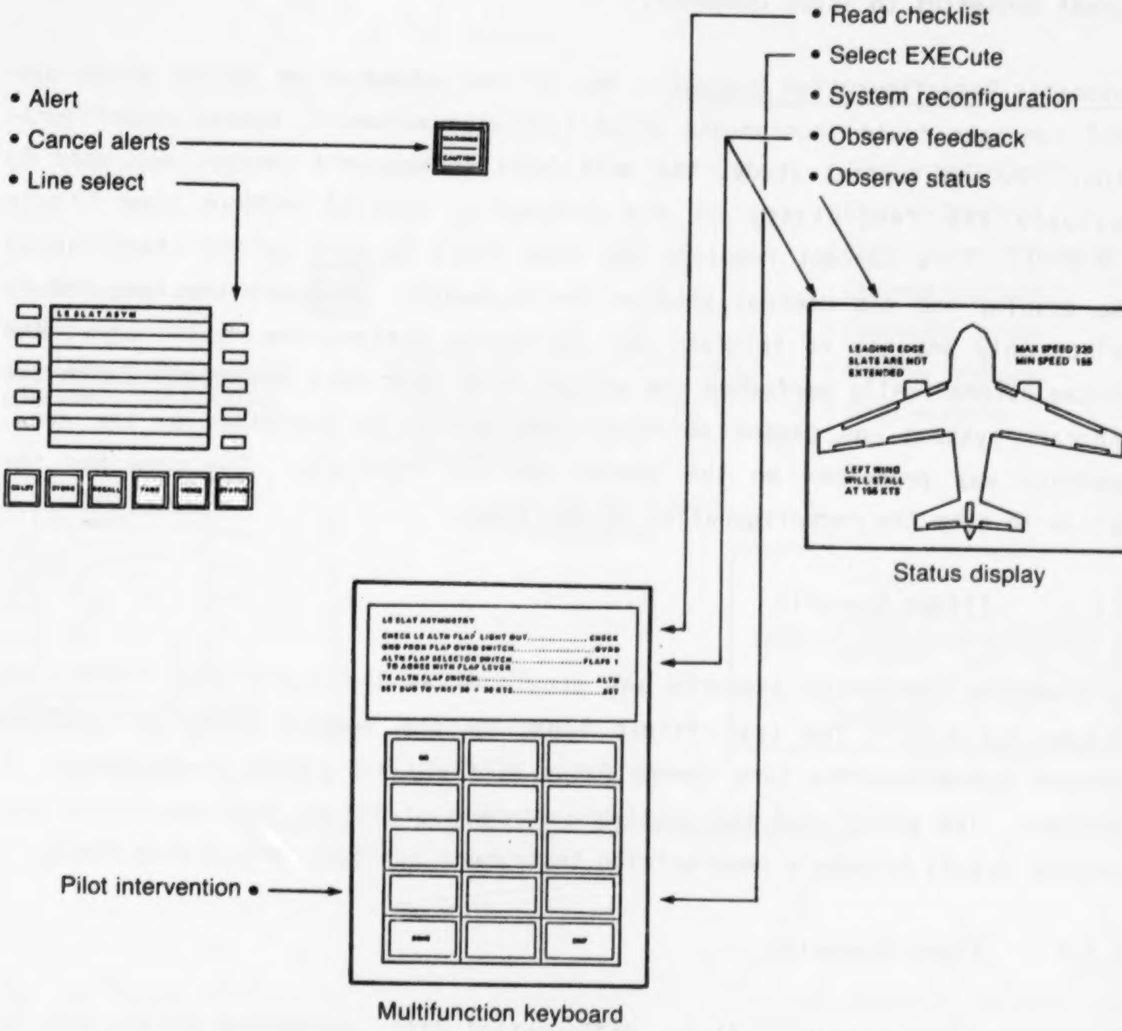

• Alert
• Cancel alerts
• Line select
LE SLAT ASYM
• Read checklist
• Select EXECute
• System reconfiguration
• Observe feedback
• Observe status
LEADING EDGE SLATS ARE NOT EXTENDED
MAX SPEED 220
MIN SPEED 186
LEFT WING WILL STALL AT 186 KTS
Status display
LE SLAT ASYMMETRY
CHECK LE ALTN FLAP LIGHT OUT........CHECK
GND PROX FLAP OVRD SWITCH........OVRD
ALTN FLAP SELECTOR SWITCH TO AGREE WITH FLAP LEVER........FLAPS 1
TE ALTN FLAP SWITCH........ALTN
SET BUG TO VREF 30 + 20 KTS........SET
Pilot intervention •
Multifunction keyboard

Figure 3.4.2-5. The Automatic Reconfiguration Concept

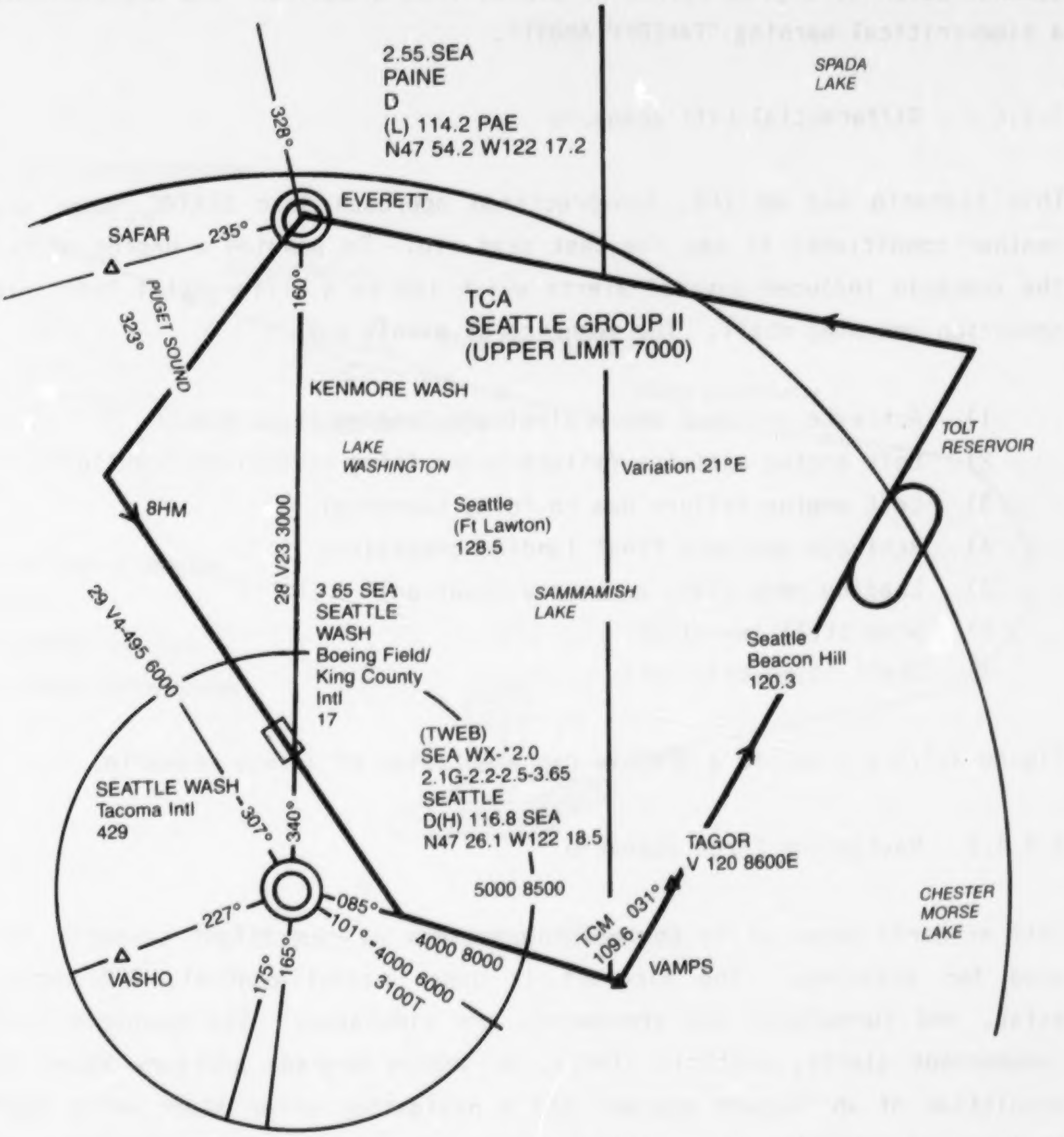

2.55.SEA
PAINE
D
(L) 114.2 PAE
N47 54.2 W122 17.2
SPADA LAKE
328°
EVERETT
SAFAR
235°
160°
323°
PUGET SOUND
TCA
SEATTLE GROUP II
(UPPER LIMIT 7000)
KENMORE WASH
LAKE WASHINGTON
Variation 21°E
TOLT RESERVOIR
8HM
28 V23 3000
Seattle
(Ft Lawton)
128.5
3 65 SEA
SEATTLE
WASH
Boeing Field/
King County
Intl
17
SAMMAMISH LAKE
29 V4-495 6000
Seattle
Beacon Hill
120.3
(TWEB)
SEA WX-*2.0
2.1G-2.2-2.5-3.65
SEATTLE
D(H) 116.8 SEA
N47 26.1 W122 18.5
SEATTLE WASH
Tacoma Intl
429
307°
340°
TAGOR
V 120 8600E
5000 8500
227°
085°
101°
4000 8000
4000 6000
3100T
165°
175°
VASHO
TCM
109.6
031°
VAMPS
CHESTER MORSE LAKE

Figure 3.4.3-1. Operational Flight Scenario

demonstration of a progression of alerts from a caution "LOW ACCELERATION" to a time-critical warning "TAKEOFF ABORT".

3.4.4.1 Differential Lift Scenario

This scenario was an IFR, non-precision approach into SEATAC under adverse weather conditions; it was the test scenario. To provide a degree of realism the scenario included several alerts which led to a differential lift critical condition and wing stall. The sequence of [illegible]nts was:

1) Activate and work the preliminary landing checklist
2) Left engine anti-ice failure under icing conditions (caution)
3) Left engine failure due to icing (warning)
4) Activate and work final landing checklist
5) Leading edge slats asymmetry (caution)
6) Wing stall (warning)
7) Stall (time-critical)

Figure 3.4.4-1 presents a graphic representation of a this scenario.

3.4.4.2 Navigation Error Scenario

This scenario occurred in the holding pattern of the flight scenario and was used for training. The aircraft is under manual control, IFR conditions exist, and turbulence and crosswinds are simulated. The scenario included independent alerts, multiple alerts, an engine degrade advisory based on the prediction of an "expert system" and a navigation error alert which degraded to a ground proximity time-critical alert. The sequence of events was:

1) Left engine degrade predictive alert (advisory)
2) Left engine overheat (caution)
3) Cabin auto inoperative (caution) and left engine fire (warning) multiple alert
4) Navigation error (caution)

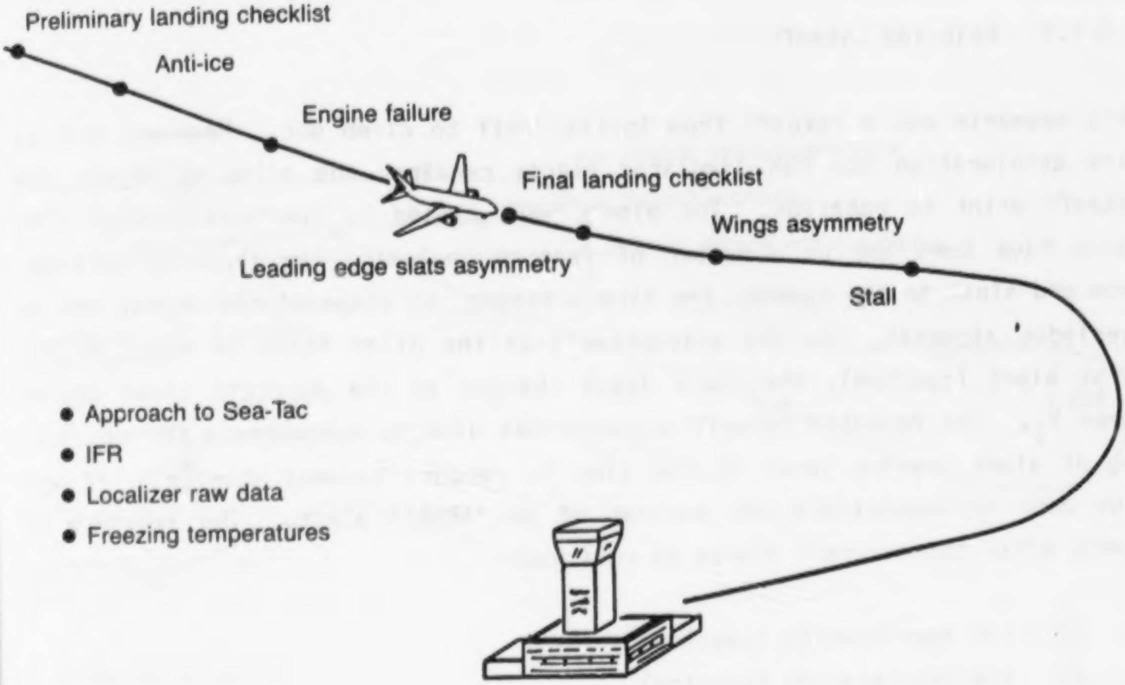

Preliminary landing checklist
Anti-ice
Engine failure
Final landing checklist
Wings asymmetry
Leading edge slats asymmetry
Stall
Approach to Sea-Tac
IFR
Localizer raw data
Freezing temperatures

Figure 3.4.4-1. Differential Lift Scenario

5) Navigation error (warning)
6) Ground prox (time-critical)

A graphic representation of this scenario is presented in Figure 3.4.4-2.

3.4.4.3 Rejected Takeoff

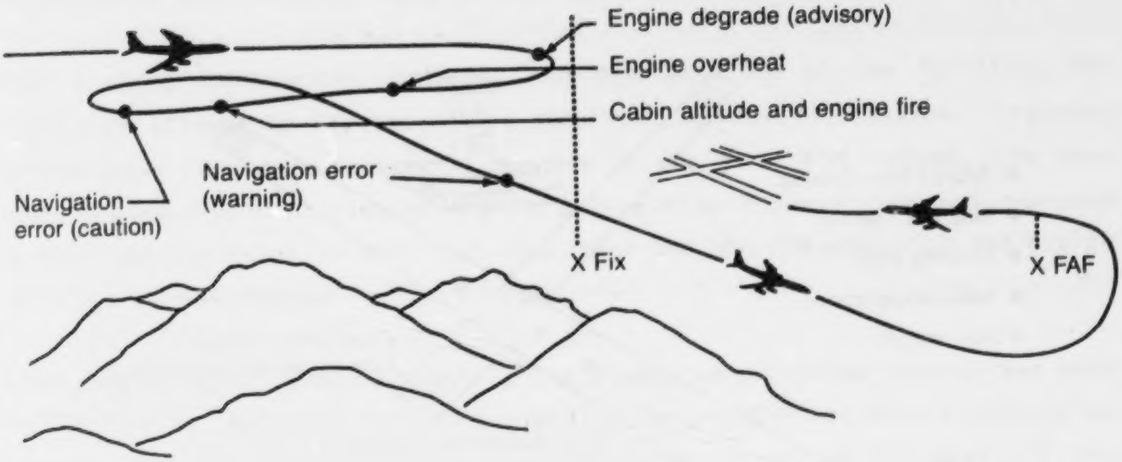
This scenario was a takeoff from initial roll to climb out. However, due t slow acceleration the FSM simulated alerts required the pilot to reject th takeoff prior to rotation. The alerts were caused by low acceleration th could have been due to a number of factors including low throttle settin snow and slush on the runway, low tire pressure, up slope of the runway and overladen aircraft. On the assumption that the pilot fails to abort on t first alert (caution), the alert level changed as the aircraft speed appr ached V_1. The rejected takeoff scenario was used to demonstrate the sequen ing of alert urgency level as the time to respond becomes shorter. It w also used to demonstrate the concept of an "ABORT" alert. The sequence events after the aircraft starts to roll was:

1) Low acceleration (caution).
2) Low acceleration (warning).
3) Takeoff abort (time-critical).

A graphic representation of the scenario is presented in Figure 3.4.4- Since the alert occurs during the takeoff role no checklist or status info mation were provided.

3.4.5 Evaluation Procedures

The system evaluation was performed by 18 experienced transport pilots were divided into 10 two-man crews (two of the pilots had to fly with an server pilot as the nonflying pilot due to the lack of a second crew membe Each crew flew four training and four test scenarios and observed one dem stration scenario. The ten flight crews flew a total of 40 training


Engine degrade (advisory)
Engine overheat
Cabin altitude and engine fire
Navigation error (warning)
Navigation error (caution)
X Fix
X FAF

- Descent to Sea-Tac
- IFR conditions
- Frontal weather

Figure 3.4.4-2. Navigation Error Scenario

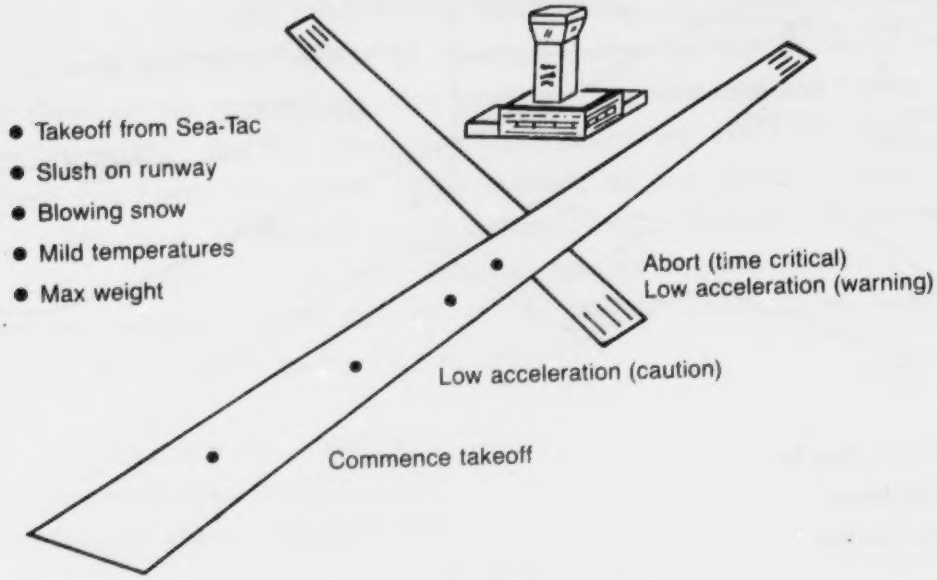

• Takeoff from Sea-Tac
• Slush on runway
• Blowing snow
• Mild temperatures
• Max weight
Abort (time critical)
Low acceleration (warning)
Low acceleration (caution)
Commence takeoff

Figure 3.4.4-3. Takeoff Abort Scenario

40 test flight segments and observed 10 demonstration scenarios. The order of presentation of the concepts was counterbalanced between the crews so that no crew received the same order of presentation. This was done in an attempt to prevent any order bias from confounding the results. Prior to the test day, each pilot was given a package of training material. This package, (Appendix B) contained a graphic presentation of each concept, operating instructions, test procedures, and a test schedule. The pilots were requested to review this material before their assigned test date.

After a short introductory briefing and demonstration of the facility, the pilots were allowed to fly the flight simulator for familiarization. Training was conducted for approximately 15 minutes on the first FSM concept. As mentioned previously, the pilot in the left seat flew the aircraft and operated the FSM, and the pilot in the right seat observed the FSM operation and evaluated the workload imposed by the system.

At the beginning of each test trial, the pilots were informed where they were in flight (i.e., approach to Boeing Field). The established crew coordination procedure for the test was that the non-flying pilot was to read all the action items from the checklist and act as a second observer while the flying pilot was to perform all the actions. The flying pilots were instructed to respond to each alert as they would in actual flight operations and to apply their best efforts not only in performing the response task, but in maintaining their flight performance. Since the simulation had no outside visual scene and a minimum of flight instrumentation and flight aids, the pilot was required to fly the designated route using a map display and make an approach to Boeing Field. The instrumentation that was available to the pilot included: a Primary Flight Display which integrated attitude, flight path, altitude and airspeed information; an EHSI which consisted of a map, heading and trend information; and electronic engine instrumentation. The flight controls that were available included: a center stick control; rudder pedals; throttle; flap control; speed brake; and the various trim controls and system panels.

At the completion of the test trials, a debriefing questionnaire was administered to the pilots to obtain a subjective evaluation of the FSM design, operation and the amount of work required to operate the system given the aircraft system controls that they just flew. The questionnaire is presented in Appendix C. At the completion of testing, the pilots were given a final questionnaire which allowed them to make comparisons between the five display and control concepts and evaluate FSM operations (see Appendix D). The test conductor performed an informal interview which allowed the pilots to expand on their questionnaire inputs.

3.4.6 Data Measurement

The data collected during the evaluation was divided into two general categories: objective data, including video and performance recordings; and subjective data, including the questionnaires and the debriefing.

Objective measures were the time required to perform the action items and the pilot's actions in operating the system. The pilot's control actions were recorded on magnetic tape and were analyzed to obtain tracking performance and the time and sequence of discrete actions. A videotape record was made to evaluate the sequence and the time of events.

Pilot opinion data was obtained not only throughout the tests by voice recording, but also after the pilots had been exposed to all five of the control and display concepts. The pilots were asked to rate each concept on an absolute basis after they had finished all the trials on that concept. This rating included questions on concept operation and workload as compared to current practices. At the completion of all the test and demonstration trials, each pilot was given an extensive debriefing questionnaire wherein they were asked to rank the different control and display concepts and to evaluate the FSM making any recommendations or changes in its design implementation or operation.

4.0 EVALUATION RESULTS

The results section is partitioned into two general sections, one addressing the FSM components and the other the system display and control components. The results of the observational and pilot opinion data are based on operating the FSM for 540 crew alerts and 80 normal procedures. The observational data were obtained from written reports of the onboard observer and from a review of the video tapes recorded throughout the test. The response time results were derived from magnetic tape recordings of 120 alerting situations and 40 of the normal procedures encountered during the test flights.

4.1 Flight Status Monitor Components

The three FSM components addressed by the pilots were: the alert display; the procedures display; and the status display. They also recommended changes to the FSM system which they felt would make it more compatible with the operational environment.

4.1.1 Alert Display

The utilization of the alert display was consistent with the results of previous alerting studies (Ref. 1,2,3). The pilots used this display to identify the specific alert that had occurred and to determine its urgency level. Most of the pilots (82%) felt that the information provided by the alert display and the expected crew actions were clear and unambiguous. After obtaining the information from the display, the crews proceeded to exercise the control capabilities of the system by line selecting the "active" alert and calling up checklists and status information. Some of the pilots (18%) reported that they at times were confused concerning the operation of the FSM controls. These comments were concentrated in two major areas: because of the alternating line select keys (odd numbered keys on the left and even on the right) the appropriate key to select an alert was not always apparent; and inclusion of keys which operated the procedures and status displays on the alerting display created confusion in identifying control functions.

4.1.2 Procedures Display

Observations made during the use of the procedures display indicated some areas that should be addressed when refining the FSM system. Although all of the checklists were procedurally correct, it was noted that in some cases the crew performed unnecessary actions that the system could have sensed and eliminated (e.g., recalling alerts as a checklist item when there were no alerts in memory). The system provided the capability to skip items in the checklist so that the crews could sequence their actions, however, they could not return to the skipped items until they completed the rest of the checklist. This feature in some cases disrupted the desired sequence. Finally, when using the monochromatic procedures display (MFK concept), coding the completed items with a symbol resulted in increased scanning to identify the completed items and the current action item.

Ninety-one percent of the pilots felt that the use of the procedures display was much better than using the Quick Reference Handbook (QRH) and that the display should be used for both normal and non-normal checklists. They felt that for warning and caution alerts the procedures display should be called up automatically and that the checklist for a new alert should be integrated with any existing checklist(s). When asked if the display could be used for functions other than FSM, 73 percent of the pilots indicated that the display should be multifunction on a noninterference basis.

Concerning the information to be presented on the procedures display, all of the pilots felt that a presentation of the action items was required along with some indication of which items had been completed. Further, 73 percent wanted critical information, such as Min/Max airspeeds or other flight limitations, to be provided as part of the checklist. Eighty-two percent of the pilots wanted the complete page on the display, because they wanted the capability to page through and read the checklist before taking action. All pilots felt that a page indication was needed for multiple page procedures. The format requested for the action items (91% of the pilots) was a reflection of that which is currently most common with the system related words on the left and the action words on the right, e.g., LEFT DEMAND HYDRAULIC PUMP......ON.

Eighty-nine percent of the pilots said that it was essential that the procedures display provide them feedback as they were performing the actions. They ranked color coding of the completed items as the most preferred method of providing this feedback. A majority of the pilots (64%) felt that the coding used in the test was appropriate while others suggested more complex schemes based on alert urgency. A preference for color coding the current action item rather than using a symbol was expressed by 82 percent of the pilots.

A voice readout of the checklists was not desired as a system component: 56 percent did not want this feature at all and 27 percent said that if it were used at all it must also have a visual display. A requirement placed on any voice readout component was that the voice message match any visually presented message.

4.1.3 Status Display

All the pilots felt that the aircraft status page was necessary for system operation and 91 percent felt that it should come up automatically (64% said before doing the checklist and 27% said after). The information that the pilots felt should be provided by the aircraft status page included: operational status of the gear, brakes, steering, tires, etc. (73%); operational status of the engines (82%); and any operational limits (82%). They felt that this information should be presented in the form of either a combination of written lists and pictorials (64%) or as written lists alone (35%). This information should have the symbols color coded according to alert urgency level and present quantitative data digitally.

Eighty-two percent of the pilots felt that the failed system status page was at least beneficial to them in understanding the situation. Seventy-three percent felt that schematics with written text should be used to present the information. They also felt that greater levels of detail should be available to the crew upon demand. Again the pilots preferred that symbols or characters be color coded according to alert urgency (73%) and that quantitative data be presented digitally (82%).

The perceived benefit of the status display was highly dependent on the type of aircraft system controls being employed. If the status display was required to operate the aircraft systems (Touch Panel concept), then all the crews perceived the display as a benefit to their response. If, on the other hand, the status display was not required to operate the systems (Basic concept), only 40 percent of the pilots felt that it was a benefit in responding to the alerts. Of the three schematic status pages (aircraft, checklist and failed system), the majority of pilots (82%) wanted to see the aircraft status page first, the failed system status page second and the checklist status page third (if at all).

4.1.4 Pilot Recommended Changes

It was observed that of all the status information available, the checklist status page and its operation caused the most concern with the test participants. This page of information was not consistently used by any of the pilots and some crews refused to use it even with prompting. The requirement to manually call up the checklist status page when it was needed to perform the action items, e.g., touch panel concept, was confusing. The crews that attempted to use the checklist status page found it very difficult to perform the required action and understand the schematic in the one second delay that was built into the system. When the delay was changed to 2.5 seconds, this problem was alleviated. Another problem that was encountered with this page was the effect of delays in switch actions on the pilots' responses. Due to transition states and other system related factors, the result of a pilot action was at times not immediately apparent. As a consequence the pilots performed multiple button pushes during these delays. It was also observed that at times the crews did not know where in the paging sequence they were. This was attributed to the lack of page numbers on the status display which also resulted in some of the crews missing the additional information that was available for some alerts.

All pilots had the opportunity to recommend changes to the FSM system which they felt would improve its capability and acceptability in the operational environment. The following are some of the changes that were recommended by more than one pilot:

1) Reduce the number of button pushes required to operate the FSM thus reducing the pilot workload and the number of memory items;

2) Improve the schematic drawings used on the status display, the information should be presented so that it is more easily understood and in a standardized manner;

3) Present the caution checklists automatically, since the caution alert requires immediate awareness, the crew should also have immediate information as to what response is expected of them so they can plan their actions;

4) Provide a dedicated switch for each status page so that the crew has direct access to the information they need at all times and include page numbers on the status pages to aid the crew in determining where they are in the status display paging scheme.

4.2 Aircraft System Display and Control Concepts

The methods used to control the aircraft systems and the type of information available for display by those systems have a significant impact on FSM architecture. It was therefore important to generate data on how the FSM was used with the various system control and display concepts to evaluate their viability in a flight deck environment. The following sections present the pilot comparisons and evaluations of these concepts along with a perceived workload evaluation and some performance data.

4.2.1 Basic System Panels

All of the pilots felt that their speed in responding to the checklists was affected by their lack of familiarity with the location of the system panels and controls. When performing the action items, none of the pilots used the checklist status page with the basic concept without prompting. The majority of the pilots (73%) questioned the necessity of presenting the checklist status information at all. They felt that it was not natural to locate a control on a system panel then look to another display for feedback while activating that control. It was felt that this process would interfere with the efficient conduct of the checklist. What the pilots wanted to see on the status display while operating the basic system panels was a presentation of the information they are required to "check" as a checklist procedure, e.g., fuel balance, flap position, oil pressure, etc., and an indication of the effect that their actions are having on the failed system.

4.2.2 Touch Panel

The touch panel concept presents a unique set of FSM design problems. Since the checklist status page is required to operate the aircraft systems, the pilots wanted that page to be presented automatically rather than requiring a manual activation. Sixty-seven percent of the pilots wanted the area to be touched to lie over the system component that will change and to be larger than was implemented. All of the pilots wanted the area that they had to touch to be highlighted so they could locate it quickly. The lack of this capability was one of the major contributing factors in the feeling of 67 percent of the pilots that the schematics provided too much detail to be effective. An important feature of the touch panel to 56 percent of the pilots was consistency between the checklist and the schematics, e.g., if the checklist item reads "LEFT ENGINE CUTOFF SWITCH.....CUTOFF" the touch area should be over a switch not a valve. If a touch panel was used to operate the systems, it was indicated by 89 percent of the pilots that the switch used to designate the completion of manual tasks (the "DONE" switch) should be presented on the touch area. Fifty-six percent of the pilots further stated that the dedicated system panels could not be eliminated by the touch panel. Finally, 67 percent of the pilots questioned the effect of turbulence on switch activation errors, especially if the touch panel is located where the crew has to reach to make an input. They felt that the location of the touch panel could be improved for both visibility and reach.

4.2.3 Voice Control

In order to achieve high accuracy, voice control systems require a training regime that was out of the scope of the present test effort. Therefore, all of the pilots were frustrated by the fact that the system did not recognize their commands with what they considered an adequate level of consistency. One important restriction that current voice control systems places on its operator is that a specific set of words must be used in a specific order for the system to function. Fifty-six percent of the pilots commented that they were not always sure what words the system expected them to use. Because of these factors, 67 percent of the pilots felt that it would be more efficient to do the actions manually rather than with voice control and they felt that voice control should not be used for this purpose.

However, if voice control was going to be used for system reconfiguration, all of the pilots said that it must be used in conjunction with some form of manual control. The functions most often mentioned as being amenable to voice control were: controlling the status display (73% of the pilots); controlling the checklist display (64%); and performing checklist action items (55%).

4.2.4 Multifunction Keyboard Control

When using the multifunction keyboard to reconfigure (with the press of the "GO" button) the aircraft systems, it was necessary to select which checklist items can be accomplished from the keyboard (e.g., turn seatbelt sign on, start the APU, etc.) and which require manual crew action (e.g., primary flight controls, gear, fire handle, etc.). A problem arises in distinguishing between the two types of action. Sixty-seven percent of the pilots commented that without using the checklist status page they could not make the distinction between the two and would prefer that this information be coded into the checklist display. Most of the pilots (82%) expressed difficulty in distinguishing between completed and incompleted action items on the monochromatic display, especially when some items were skipped. They also felt that it took much longer to find the current action item on the monochromatic display than it did on the color display. In order to verify their keystrokes and associate them with the active line of the checklist, 82 percent of the pilots wanted the active checklist item to be repeated on the multilegend key face.

4.2.5 Automatic Reconfiguration

The major concern of all the pilots regarding automatic reconfiguration was reliability. As with any other automatic system, it must have a very low probability of failure before the pilots will feel comfortable about using it. Another major concern of the pilots was the question of who had the responsibility for performing what actions (pilot vs. automatic) and who is going to make the task assignments. It was the general feeling that the pilots should have the responsibility for the major action items (flight controls, fire handle, engine shutdown, etc.) and the automatic system for "clean-up" functions (e.g., APU start, isolation valves, etc.). This philosophy was reflected in the features that the pilots wanted to see in an automatic system which include: the automatic system stopping before critical action items (100% of the pilots); ability to stop the sequence manually at any time (82%); selection of the automatic function should be a crew option (73%); the automatic sequence should stop when a new alert occurs (73%); and system status should be presented which reflects any reconfiguration (73%). After reviewing the automatic concept, 56 percent of the pilots volunteered that they felt it would be a means to eliminate errors in doing the checklists. Further study of the criteria for selecting automatic tasks was suggested.

4.2.6 Subjective Comparison of the Concepts

The pilots were asked to evaluate the system display and control concepts on a number of different criteria and then to take a specific set of these criteria and rank order the concepts. Figure 4.2.6-1 presents graphically the evaluation data in the form of average pilot ratings. These data indicate that, with the exception of voice control, all the concepts were rated above average (i.e., above 5.0) on all criteria. Due to operational difficulties, voice control was rated below average on: the acceptability of the concept (4.4); the implementation in the simulator (4.9); its ease of use (4.5); its potential for error reduction (4.5); and its compatibility with the operational environment (3.8). All the other concepts received the same general ratings across the criteria. The rating trend, however, consistently placed the automatic reconfiguration concept higher on the scale than the others. This was especially true for the following: its ease of use (8.0); its potential for error

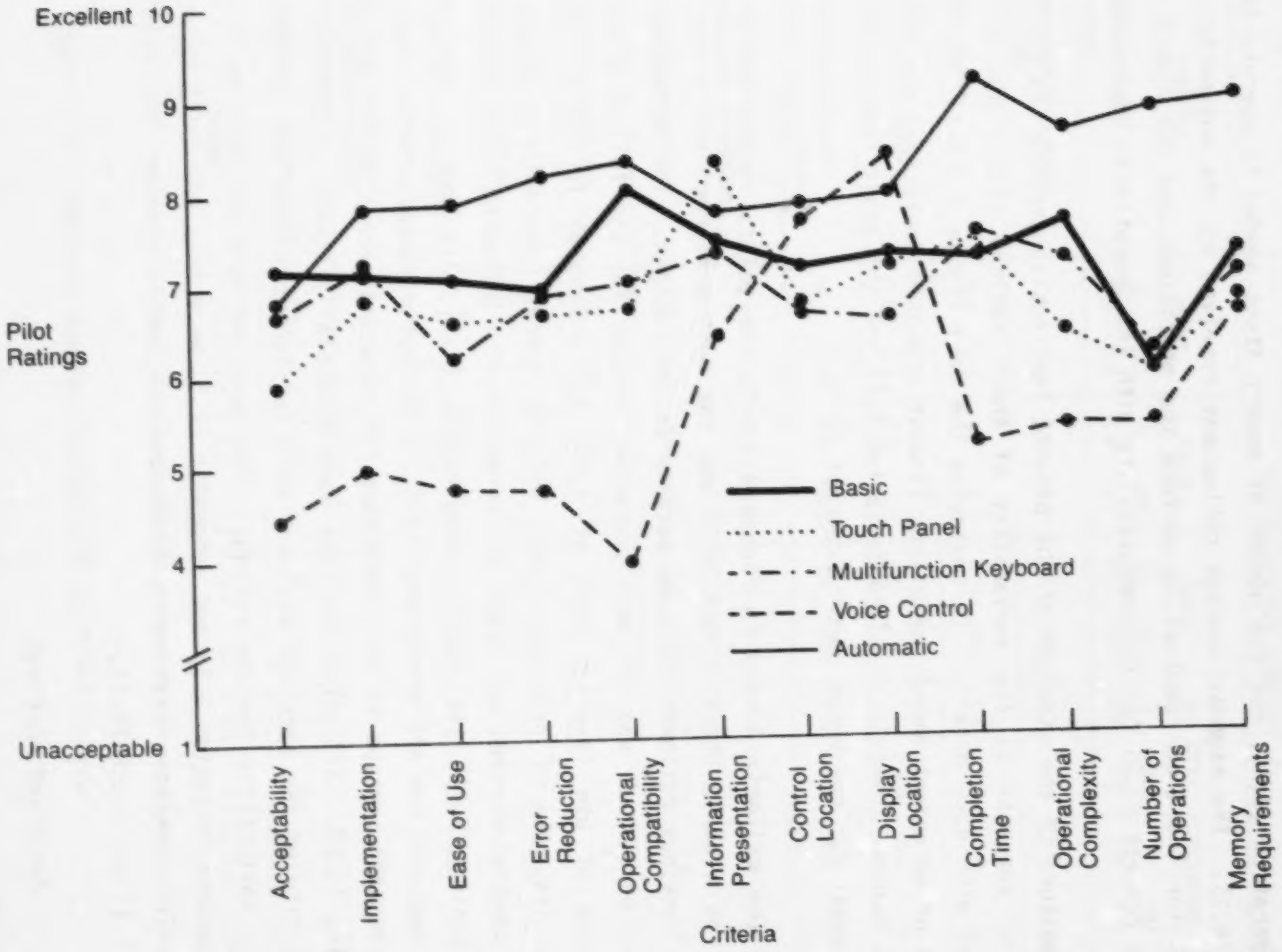


Figure 4.2.6-1. Pilot Evaluation of the Aircraft System Control Concepts

reduction (8.4); the time required to complete operations (9.3); the complexity of operating the system (8.6); the number of actions required to complete an operation (9.0); and the number of memory items needed to operate the system (9.1). The highest average rating was received by the automatic concept (9.3) for the time required to perform the operations and the lowest by the voice concept (3.8) for its compatibility with the operational environment.

One measure of the strength of the pilots' feelings concerning the display and control concepts is the variability of their ratings (i.e., how well they agreed with each other). In reviewing the data (Table 4.2.6-1), the highest level of agreement among the pilots (lowest standard deviation) was the automatic concept (overall standard deviation 1.4) and the basic concept (1.7) and the lowest for the voice control concept (2.7).

Using the criteria listed in Figure 4.2.6-2, the pilots ranked all the concepts on a scale where a rank of 5 was the most preferred and 1 the least. These rankings followed the same pattern as the ratings. The automatic reconfiguration concept was the most preferred concept for the following criteria; its ease of use (average rank of 4.5); its potential for error reduction (4.3); its ease of training (4.2); and its overall operability (4.1). The voice control concept was least preferred for the following criteria; its ease of training (1.7); its overall operability (2.1); its overall desirability (2.0) and the overall preference (2.0). The basic concept ranked just below the automatic concept in its: potential for reducing errors (3.4); and ease of training (3.6). All other rankings were essentially equal. Furthermore, the variability of the rankings was much more consistent across the concepts than was the variability for the ratings. The most variable concepts basic (overall standard deviation 1.3) and automatic (1.3) were only one tenth of a ranking position greater than voice (1.2) and two tenths greater than multifunction (1.1) and touch (1.1).

4.2.7 Perceived Workload

The pilots were asked to compare the workload imposed by the test systems to their current flight operations on a 7 point scale where the low end of the scale (1) meant that the new concepts are much harder/worse than the current

CRITERIA	SYSTEM CONTROL CONCEPT									
	Basic		Touch Panel		Voice		Multifunction CDU		Automatic	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
a. Acceptability of the concept	*7.3	2.0	6.3	2.7	4.4	2.6	6.8	1.9	7.4	2.6
b. Implementation in the simulator	7.1	1.9	6.9	1.8	4.9	2.8	7.1	1.4	8.0	1.1
c. Ease of use	7.1	1.5	6.5	2.1	4.5	3.0	6.5	1.9	8.0	1.5
d. Reduction in error potential	7.0	2.0	6.5	2.6	4.5	3.0	6.9	1.9	8.4	1.8
e. Compatability with operational environment	8.0	1.4	6.6	3.3	3.8	2.9	7.0	2.0	8.5	0.9
f. Amount and type of information presented	7.4	2.7	8.4	1.2	6.3	2.7	7.4	1.5	7.9	1.2
g. Location of controls	7.1	1.9	6.6	3.1	7.5	3.0	6.8	2.0	7.9	1.8
h. Location of displays	7.3	2.0	7.3	2.2	8.0	1.9	6.6	1.9	8.1	2.0
i. Time required to complete procedure	7.1	1.1	7.3	1.9	5.1	2.7	7.5	1.7	9.3	0.8
j. Operational complexity	7.5	1.4	6.4	2.1	5.4	3.0	7.0	2.0	8.6	1.0
k. Number of physical operations required	5.8	0.8	5.8	2.3	5.4	2.4	6.0	2.4	9.0	1.1
l. Number of memory steps	7.3	1.9	6.6	2.6	6.1	1.9	7.3	2.6	9.1	1.1
Overall	7.2	1.7	6.8	2.3	5.5	2.7	6.9	1.9	8.4	1.4

*Scale values — 10 = excellent, 1 = unacceptable

Table 4.2.6-1. Mean and Standard Deviations of the Pilot Evaluation

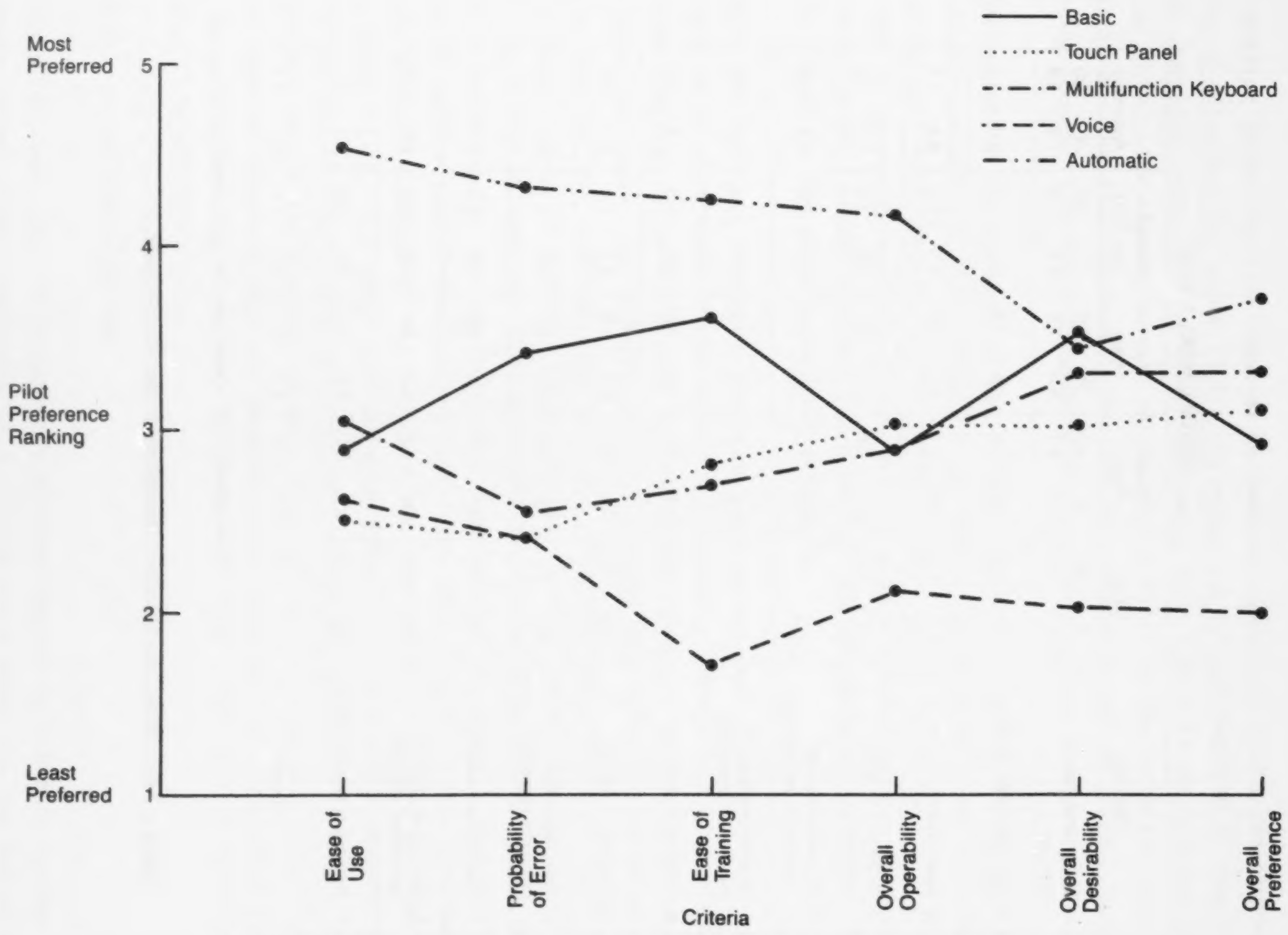


Figure 4.2.6-2. Preference Rankings for the System Display and Control Concepts

operation and the high end (7) meant that the new concepts are much easier/better. The interpretation of the results of this area of questioning must be made realizing that the operating procedure of the test which required the flying pilot to perform the action items is not realistic in an operational sense. Operationally the action items would be split between the flying and non-flying pilots. Therefore, the test procedures as flown may have had the effect of artificially increasing perceived workload. Even with this design artifact, all of the system control concepts had an average rating indicating that they were easier/better than current system operation (Figure 4.2.7-1). The results from the individual pilot groups reflect the airline pilots consistantly rated the workload of the control concepts as easier than their present operations while the certification pilots rated it the same or harder.

Figure 4.2.7-2 presents the criteria that were used to estimate workload. These results reflect the effect of having the flying pilot perform all the action items as can be seen with the lowest ratings for each concept being the ability to maintain piloting functions and the overall workload. Except for these two criteria all other ratings indicated that the test concepts were easier/better than current operations.

The comments by the majority of the pilots (i.e., all comments were given by more than 50% of the tested pilots; some, however, may have a higher percentage) concerning the workload imposed by the test concepts indicate that they want to divide the performance of the action items so that the flying pilot would do those items related to aircraft control and the non-flying pilot would perform system control items. They also felt that unfamiliarity with the simulated aircraft, the FSM and the system controls, resulted in an increase in their perceived workload. They felt that the number of pilot actions to operate the system, e.g., button pushes to display a caution checklist, button pushes to page through the status information, sequencing status pages, etc., produced unnecessary workload. The feeling was expressed that some of these unnecessary actions could be eliminated by automating some of the FSM functions such as displaying the checklist for cautions without requiring a line select and automatically sequencing to the appropriate status page. The use of the checklist status page was also seen as an unnecessary

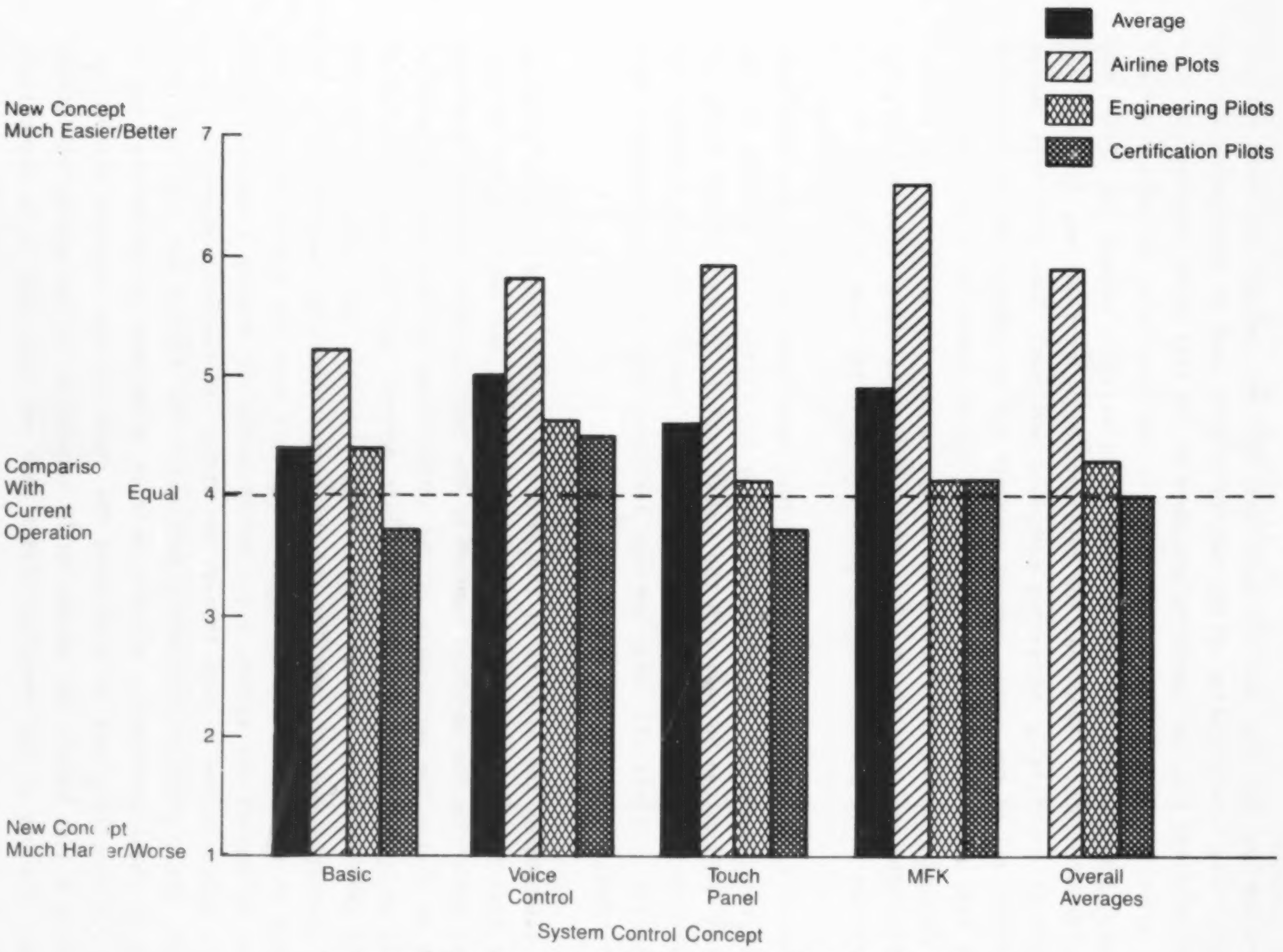


Figure 4.2.7-1. Average Perceived Workload Partitioned by Pilot Group

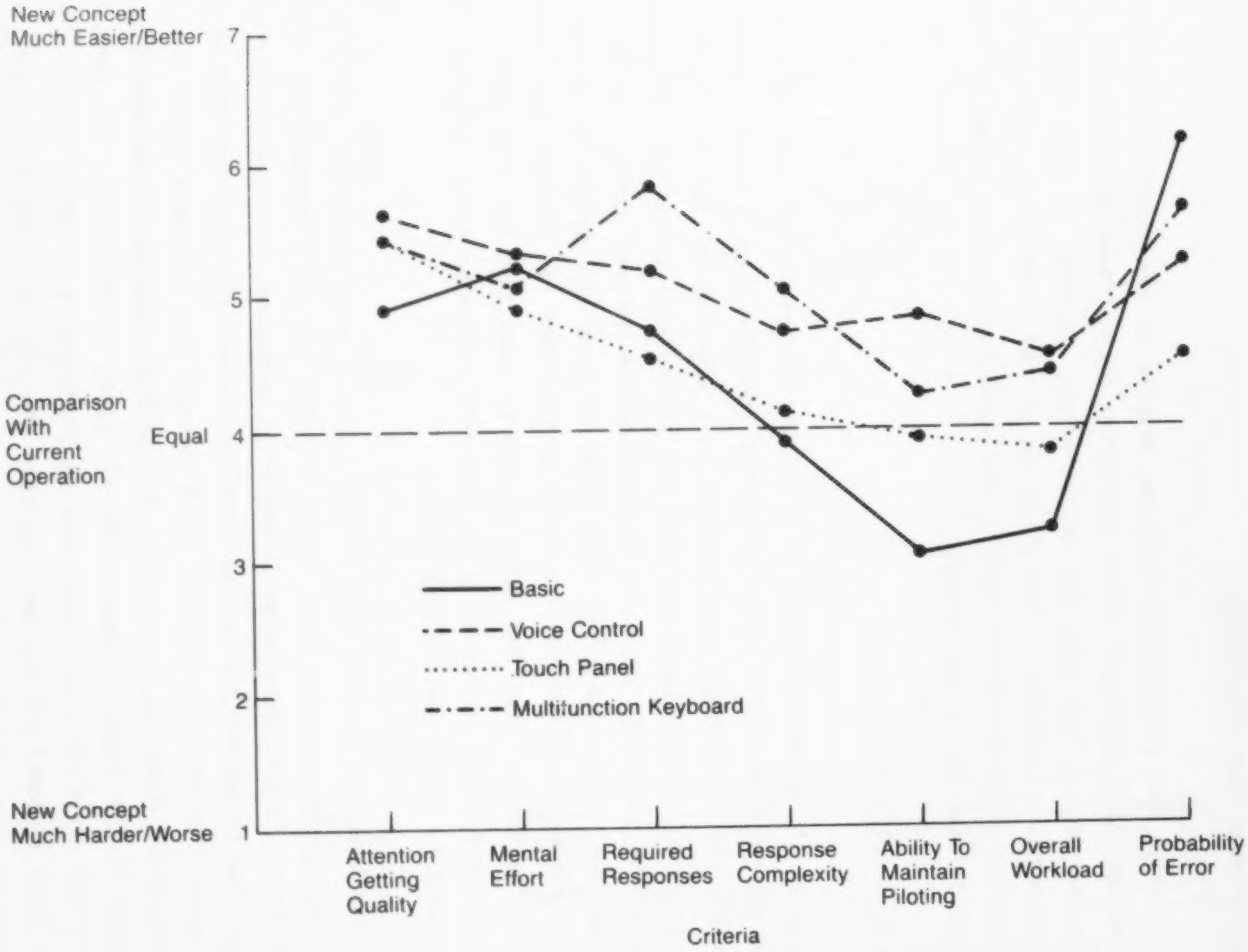


Figure 4.2.7-2. Perceived Workload Comparison

addition to the workload. The pilots expressed the feeling that they did not want or need that information.

Conversely, the pilots felt that the display of the checklist significantly decreased their workload. Color coding the action items decreased the time to scan the display and also the mental effort required to keep track of the whole response process. Centralization of the information (both procedural and status) reduced overall scanning and permitted the crew to get all the pertinent information in one location.

4.2.8 Pilot Performance

A measure of the effectiveness of a control concept is the time taken to perform the required action items using that concept. Figure 4.2.8-1 graphically presents the performance data from the test scenario for the four tested concepts (basic, voice, touch and MFK) and an analytic number for the automatic system. The value for automatic performance was derived using a value of 2.5 seconds for system functions (the time it took the system to perform the action steps) and 10 seconds for pilot action items (an average time for pilot "check" actions). From the data, it can be seen that the time used to complete action items is dependent on both the variables being examined, i.e., alert urgency and system control concept.

The data from the present study (Table 4.2.8-1) were consistant with previous alerting system research (Ref. 1,2,3) in that the alert urgency had a direct relationship to the speed in which the pilot responded. The overall average response time to perform the action items in the warning checklist (8.5 seconds) was faster than that for cautions (10.5 seconds) and both were faster than normal checklist items (12.5 seconds). As would be expected the automatic system resulted in the fastest response for all types of checklist. In performing the normal checklists the touch concept producing a slightly faster average time (12.8 seconds) per action item than the MFK (14.1 seconds) basic (14.6 seconds) or voice (14.8 seconds) concepts. Performance of the abnormal checklists resulted in some definite trends with voice control exhibiting the slowest average item response times for both warnings (10.8 seconds) and cautions

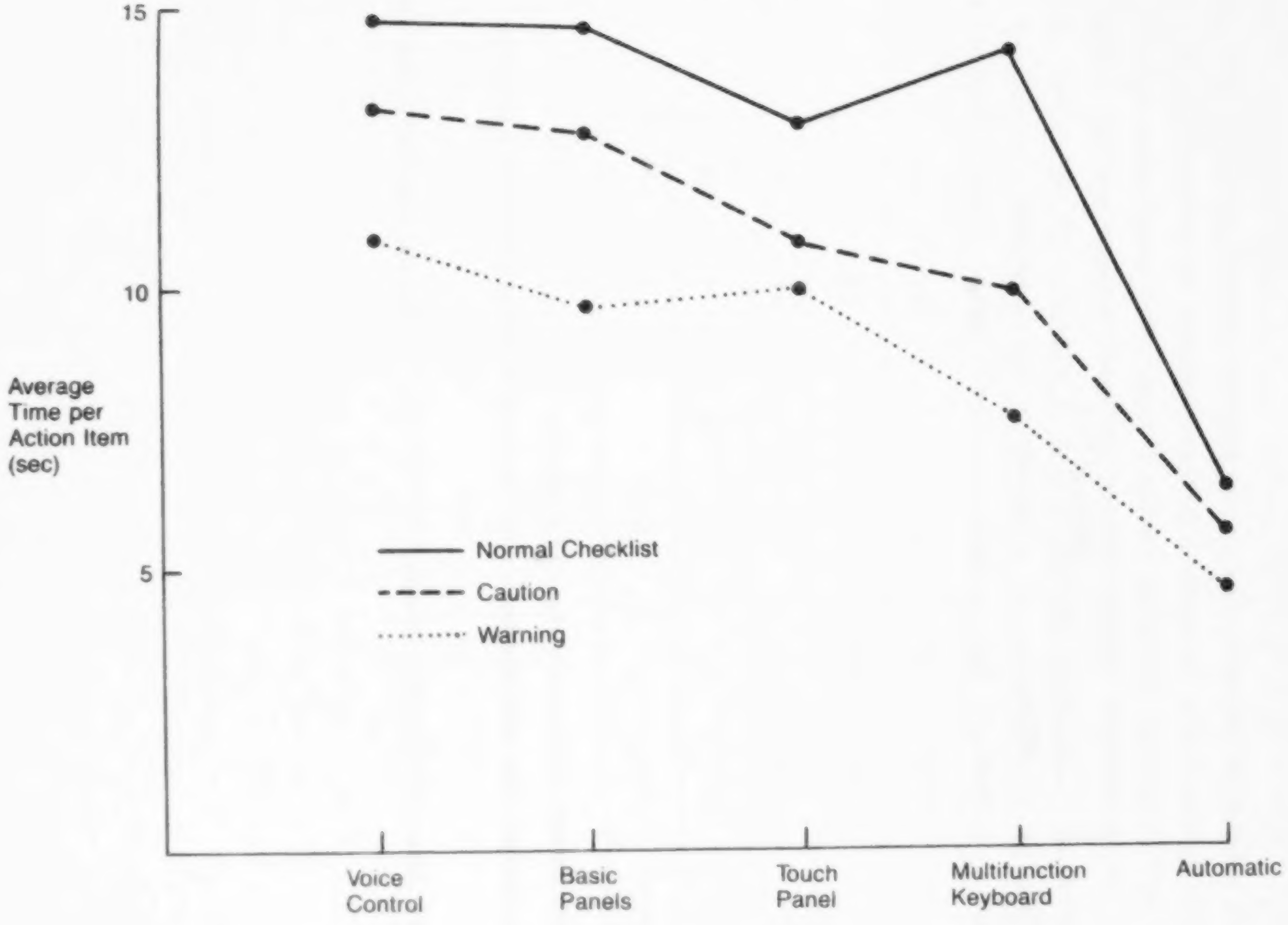


Figure 4.2.8-1. Average To Complete a Checklist Item as a Function of Alert Urgency and System Control

SYSTEM CONTROL CONCEPT	CHECKLIST TYPE					
	NORMAL		CAUTION		WARNING	
	MEAN	S.D.	MEAN	S.D	MEAN	S.D.
Voice	*14.8	3.2	13.3	4.1	10.8	2.0
Basic	14.6	2.6	12.8	2.8	9.6	1.3
Touch	12.8	1.3	10.8	2.7	10.0	1.7
MFK	14.1	1.7	9.9	2.8	7.7	2.0
**Automatic	6.2		5.5		4.5	

*Means and standard deviation are presented in seconds

**Automatic concept times were analytically determined and no standard deviation is presented

Tabe 4.2.8-1. Mean and Standard Deviations for the Time To Complete Checklist Action Items

(13.3 seconds) and the multifunction keyboard the fastest (7.7 and 9.9 seconds, respectively).

Except for the voice control concept which was affected by errors in recognition, the variability of response was in a range of a 1.3 seconds standard deviation for using touch panel with a normal checklist and using the basic system panels for the warning checklist to 2.8 seconds standard deviation for using the basic and MFK concepts with the caution checklist. The completion of the caution checklist produced the highest variability with an average standard deviation of 3.1 seconds and warning checklists the lowest at 1.7 seconds.

5.0 DISCUSSION AND CONCLUSIONS

The ability of the flight status monitor to provide guidance and feedback along with the alerting functions offers the potential of enhancing aircraft safety by improving the effectiveness of the flight crews in both normal and non-normal situations. It achieves this potential by reducing the probability of error, the time to respond and the perceived workload while making more of the crews' channel capacity available for flying the aircraft. The following sections will discuss the study findings for each FSM component and relate them to system implementation.

5.1 Alert Display

Because of its central location and coding of the information, this display was seen as facilitating the pilot response to alerts. This component of the FSM provides the means for the crew to determine "what" is wrong and therefore, it must be designed to transfer that information effectively. There was nothing in the present test that indicated that the guidelines for the alert display established in the Alerting Systems Standardization Study (Ref. 3) should be changed.

In the flight operations environment it is necessary for the crew to interact with the FSM alert component. The controls required for this crew interaction include: a method of storing caution and advisory alerts that remain after working their checklists; a method of recalling stored alerts; a method of paging the display when the number of alerts exceeds the capacity of a single page; and the capability of selecting a specific alert(s) to perform some system action, e.g., call up the checklist, get handbook information, perform a selective store, etc. If the method of selecting a specific alert(s) is via switches located next to the line to be selected, then some cue should be used to make it very clear what alert line goes with what switch.

5.2 Procedures Display

Almost all of the pilots tested noted the benefit of the procedures display in working both normal and non-normal checklists. They preferred it to the Quick

Reference Handbook, because it aided them in performing the procedure by presenting the appropriate steps and keeping track of what had been accomplished. This display therefore, was identified as a necessary component of the flight status monitor with the function of providing the majority of the guidance information.

The results indicate that the pilots want to use the checklists to plan their course of action. In order to accomplish this planning, the complete checklist of action items and relevant flight information (e.g., diversions, flight limitations, max speeds, min speeds, etc.) should be available for pilot review. In current operation the handbook checklists are generally formatted so that the action system is on the left and the action step is on the right, e.g., LEFT DEMAND HYDRAULIC PUMP..............ON. This same format was considered appropriate for the procedures display because of its familiarity and the fact that it fits the way the crews communicate the action items.

In operating the FSM, the crews identified an additional set of information that they felt should be included on the display in order for them to effectively respond to the checklists. They felt that the display should provide an indication of: the alert(s) being addressed and its (their) urgency level; what page is currently being displayed; which action item is the next one to be accomplished; and which action items have been completed or are currently in transit. In order for the pilot to know that the system is operating, the indication of a completed action or an "in transit" item should be made in as short a time frame as possible. If these indications take longer than 0.5 seconds, the pilot will have a tendency to perform the action again. He will also feel that the system is too slow for effective checklist performance. In some cases the pilot will perform or may have already performed some of the required actions before looking at the checklist. In these instances, the items should be identified as completed. Almost all the pilots felt that the feedback provided by these indicators was essential for system operation and that color coding was the preferred method of providing the feedback where appropriate.

Since it is a computer based (and most likely artificial intelligence based) system, the FSM should have the capability to formulate, integrate and modify checklists according to the situation. Because of the requirement to have all the checklist steps available for the crew to review, it is very important that the checklist be limited to only those actions which are necessary. The crews expressed concern that a sophisticated information system would not be able to tailor the checklists to the specific situations. The FSM should have the capability to eliminate unnecessary action items from the checklist, for example, the action item "ALERTS................RECALL" is not necessary if there are no alerts in the FSM memory. Because the current method of presenting checklists is not dynamic, "IF" statements are used to accommodate all contingencies, for example, "IF ALTITUDE BELOW 35000 FEET, APU.........START". These kind of statements should not be required on the FSM, because the system is monitoring aircraft parameters and can determine the appropriate action statement. Finally, when situations occur that cause multiple checklists, the system should have the capability to integrate those checklists, prioritizing the action items, and eliminating duplication.

The guidance component display characteristics should follow the design guidelines documented in the Aircraft Alerting Systems Standardization Study (Ref. 3). Although voice presentation is recommended when rapid response is required and it does transfer workload from the visual to the auditory channel, the system designer must be aware of the serial presentation requirements of the auditory channel. A large body of research has shown the significant potential for the interference between different voice sources. The majority of the pilots recommended that voice read-out of the action items not be included as a system capability. The pilots that were tested did feel that the procedures display could be used for other display functions as long as it was on a noninterference basis.

In order for the crew to interact with the guidance component, the system controls should provide the capability to: select checklists not only for the current alerts, but also normal procedures associated with the current flight phase and any other normal or non-normal procedure that the crew wishes to review to; page the checklists forward and reverse in order to accommodate those procedures which require more than one page; of selecting a different sequence of action based on their knowledge of the situation by moving the current action item indicator up and down; and to signal the completion of action items which the system expects the pilot to perform, e.g., check seatbelt and shoulder harness.

5.3 Status Display

The results indicate that the status display is beneficial to the operation of the flight status monitor. The status display provides the majority of the FSM feedback function by presenting the crew with an indication of the overall status of their aircraft as well as informing them of the status of failed systems and providing handbook information for dealing with non-normal situations. The requirement for presenting the schematic which corresponds to the current action item of the checklist (checklist status page) is dependent upon the type of aircraft system controls being employed.

All the crews that were tested felt that the aircraft status information was necessary for system operations. The aircraft status page should be used to present any operational limitation of the aircraft as well as the status of engines, flight control surfaces, gear, brakes, steering, and tires. This page should activate automatically when a non-normal situation occurs which requires immediate attention or action. It may be presented automatically at flight phase changes and should be available at all times for manual activation. The information on the page should be continuously updated so that the crew can obtain current status without any additional actions.

The format of the aircraft status display is very important relative to the amount of information that is transferred to the crew. Because of the amount and type of information to be included on the aircraft status page, both alphanumerics and graphic techniques are appropriate. The use of graphics facilitates the rapid presentation of a large quantity of disparate information in a limited space while promoting situational awareness. Research has shown that pilots can interpret properly constructed graphics quicker than corresponding written material (Ref. 2,4). The pilots indicated that as an aid to interpretation the graphic presentation should be color coded and the code should include an indication of the alert urgency. There is however, some information that is more amenable to alphanumeric presentation such as max/min limitations, special instructions (e.g., avoid icing), and quantative information.

Any quantitative information that is provided should be in digital form unless the crew requires some sense of rate or more situational awareness than an analog presentation would be more appropriate.

The failed system status page is the next level of detail in a non-normal situation. It is used to provide the crew a more comprehensive understanding of the situation. At the top level the information should make the crew aware of the system that has failed and its effect on other major aircraft systems, e.g., flow diagram, pressures, temperatures, electrical output, etc. Again the failed system status should be presented both graphically and alphanumerically with the symbols or characters color coded according to alert urgency and quantitative information in digital form. There may be some situations which require more detail about the failure for the crew to respond effectively. The FSM therefore, should have the capability to present levels of greater detail about the failed system upon crew request.

The information pages of the status display provide the crew with supplemental information from the flight manual about non-normal situations. Operationally the crews used this page after they had completed the checklist and had the situation stabilized. The time pressure for using the information presented on the information page(s) is relatively low since it is not required to respond to the alert. Therefore, alphanumeric presentation of the information is appropriate. Because it is supplemental information, there is no need to bring it up automatically, but it should be available whenever the crew wants to activate it manually.

The checklist status page resulted in the most variability among the crews in their operation of the system. While some crews used it under protest, others refused to use it at all except to operate the touch panel. The complaints centered around the usefulness of the information for any of the aircraft system control concepts (except for the touch panel) and that it was a waste of time trying to determine what was being presented while they were trying to work through the checklist. If the controls require interaction with the status display, i.e., touch panel, then the checklist status page is necessary.

owever, this page should not be used unless it is required for aircraft sys- em control. If the checklists status page is required to operate the air- aft systems, then every effort should be made to make the crew responses ccurate and timely. The status page should be activated automatically with he diagrams sequencing with the action items on the checklist. Information hat the pilot needs to accomplish "check" items, e.g., fuel balance, ltimeter, etc., and a control that is used by the pilots to indicate the ompletion of their action items should be included on the checklist status age. The results of the crew actions should be quickly presented (less than .5 seconds) on the status display. The diagrams should remain long enough fter each action for the pilot to observe the results of his action.

s the feedback component of the flight status monitor, the status display hould have characteristics which are in accordance with the guideline present- d in the Aircraft Alerting Systems Standardization Study (Ref. 3). All of he features of the display should be designed to facilitate the transfer of he highly complex information concerning the aircraft and aircraft systems tatus to the crew in an effective manner. Color was the preferred method of oding the information. Schematics and graphics, when conbined with a elective use of alphanumerics, was the format that most effectively ransmitted the desired information. Because of the number of different types f information available on the status display, each page should be clearly abeled to permit easy access. The sub-pages should also be labeled so that he crew can immediately determine what page is being presented.

or the crew to interact with the feedback component, the system controls hould provide the capability to: activate the status display at any time uring the flight so that the crew can tailor their information gathering to he flight situation; select the particular status page that is required with- ut unnecessary button pushes, thus reducing the crew workload encountered in sing the system; page through the sub-pages to obtain all the available infor- ation; and to select greater detail on the failed system status page. Given hese controls the crew should be able to utilize the status display to its ullest capability.

5.4 Aircraft System Controls

During the study, the flight status monitor was combined with five different concepts for controlling the aircraft systems. The combination demonstrated that the design of the FSM is effected by the system control concept being employed. Because system control is so aircraft-design specific, the FSM must be designed to accommodate a wide range of design concepts. Furthermore, the advanced technology used to operate the aircraft systems is applicable for use as system control for the FSM.

.0 RECOMMENDATIONS FOR FUTURE ACTIVITY

.1 FSM/Pilot Interface

he Phase I and II efforts have identified a number of issues concerning the light status monitor pilot interface which need to be resolved before any eaningful guidelines can be written. Table 6.1-1 presents a partial list of hese issues. One of the objectives of any future program activity should be o resolve these issues in an integrated testing activity. One of the major ctivities of such an effort would be the investigation of the time-critical lerts. The near-term requirements for additional time-critical alerting capaility for collision-avoidance, windshear, takeoff abort, and perhaps active ontrol(s) failures are becoming more pressing. Previous research has shown hat the manner in which this type of information is presented to the pilot is ritical. Improperly designed displays can confuse and impede pilot response, hereas properly designed displays can elicit rapid and accurate responses. dentification of the proper display location (dedicated display vs. elecronic flight instruments) and the development of formats is one of the critial FSM issues. The results of this activity should then be used to modify nd update the Phase II FSM implementation.

he updated FSM should then be installed in a full mission simulator to evaluate it as part of an integrated flight deck. A comparison should be made beween the crew performance when using the FSM and performance when using conventional alerting components (i.e., distributed annunciators and status infornation). This comparison will permit the validation of the FSM concept and an indication of the ways (if any) which the FSM can aid the crew.

.2 FSM/Aircraft Interface

In order for the flight status monitor to be effective it must be able to gather and process large amounts of information about the aircraft. Any alert which is presented to the crew must be generated from this data. Any guidance generated by the FSM in response to a non-normal situation must have its basis in the data stored and sensed by the system. Any feedback to the crew as a result of their response must reflect changes in the sensed data and the

ALERT DISPLAY
- Prioritization
- Inhibition
- Multiple alerts
- Predictive Alerts

PROCEDURES DISPLAY
- Number of checklist steps displayed
- Coding schemes (color and monochrome)
- Display format
- Operational consideration (menu, paging, etc.)
- Action item integration (how, where, etc.)
- Control technology (line select, touch, voice, etc.)

STATUS DISPLAY
- Number of pages
- Information presentation (graphics vs. alphanumerics)
- Display format (plan view, side view, analog, digital, etc.)
- Amount of information provided per page
- Operational considerations (automatic page select, menu, etc.)
- Controls technology

INTEGRATED FSM SYSTEM
- Display of intransit actions
- Identify holes in alerting system guidelines
- Integrating the time-critical display with electronic flight instruments
- Expert system applications

Table 6.1-1. Unresolved FSM Issues

effect that those changes have on the situation. Therefore, the information flow and processing will comprise a large part of the FSM system. As has been discussed in previous studies (Ref. 4,5) it is projected that for future generation aircraft there will be an integration of flight management, flight control, fault monitoring, maintenance data recording, sensor subsystem navigation and communication. The interchange of data between these sources could provide a pool of information with which to determine overall aircraft status. The major study area relative to this integration is to define the type of logic required to process the data and to provide the crew with the appropriate information to perform their flight task.

Traditional computing which requires well structured problems with algorithmic solutions based on full information with a single correct answer may not be amenable to the flight status monitor operation. What may be required for effective operation is some application of artificial intelligence which can work with ill structured problems which require a search for a solution and can use incomplete information to arrive at a probablistic answer. The term artificial intelligence is used to designate any attempt to automate or evaluate human type reasoning. Although there are many subfields of artificial intelligence, the one most applicable to the FSM is the field of expert systems. This system would use a specialized knowledge base to make decisions, manipulating that knowledge to perform at a level comparable to a human expert for a specific situation. In other words, the system will have a knowledge base that has been gathered from experts (pilots, design engineers, safety inspectors, etc.) and will be able to tap and relate that information to the flight situation in a timely manner.

Some of the issue that need to be resolved about expert systems should include:

1) A definition of the scope of the knowledge base. In order to respond to the wide range of non-normal situations and to provide the predictive capabilities and flight phase adaptation, a comprehensive knowledge base is required. The size and design criteria for this data base should be investigated.

2) Establish the expert pool for building the knowledge base. The FSM operation will be tailored to each individual aircraft and therefore, it will be necessary to identify what types of experts should be used to input to the knowledge base. To accomplish this objective it will also be necessary to develop a scheme to integrate the data from a number of different experts to provide a single meaningful output.

3) Identify the alert set. It may not be possible to identify and address every combination of events that may occur. Therefore, a set of criteria should be developed to identify alert situations for which the system will provide crew guidance.

4) Investigate operational and design considerations with respect to their impact on system sensors and the potential FSM operation. There may not be sensors available to provide some of the data that the system may require to provide the crew with appropriate information about some specific situations.

5) Define the prioritization and inhibition schemes and how they will be implemented. There are situations during flight operations when some information should be inhibited (e.g., the large number of alerts that could be associated with an engine failure). These situations should be investigated and some guidelines developed. Prioritization of alerts and checklist steps will require a set of rules for implementation.

6) Determine the impact of arriving at probabilistic answers (a feature of expert systems) on system reliability definitions. Since the expert system is designed to be able to arrive at an answer based on partial or incomplete information, a study should be done as to the effect of this process on the overall system reliability figures and how that impacts the certification process.

7. Develop a plan and criteria for the test and certification of expert systems.

As can be seen from these issues, an in depth study of the application of expert system technology to the FSM is needed to address the many implementation questions.

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APPENDIX A

TEST FACILITIES

A.0 FACILITIES

One of the most important aspects of any applied testing program is the selection and development of the test facility that will be used to perform the evaluation. The environment created by the facility must be realistic enough to generate data which satisfy test objectives. In the present study, the technologies being evaluated required a facility capable of supporting advanced controls and displays and providing a realiistic environment for their evaluation. The following sections describe the test facility and FSM components used in the study program.

A.1 Flight Deck Research Mockup and Integration Laboratory

The Mockup and Integration Laboratory (Figure A.1-1) is a basic engineering laboratory providing R & D capability that facilitates the progressive evolution of new display and control concepts. It has been established and, in turn, expanded: to provide for systematic increases in both simulation and technological capabilities; and to provide part-task demonstration, and evaluation. This laboratory provides capabilities to support (1) early laboratory work requiring use of bench development and test facilities, (2) successive stages of partial simulation using simplified approximations of sensor and aircraft systems, and (3) concept implementation in a full-up simulator to confirm appropriateness of interface provisions and operations prior to flight testing.

The laboratory includes an all-electronic cab with a full set of displays, representing those display technologies expected to be available and matured by 1990. The cab has been developed to fulfill a dual purpose. First, the cab provides a facility to appraise the requirements for an individual display or control, including the display content, i.e., what information is needed. It also permits preliminary appraisal of dynamic display formats to ensure that the pilot receives the information easily and without error. Secondly, the cab provides the facility to initiate systems integration which is necessary in the development of new displays and controls. The cab can facilitate an appraisal of the degree with which a new display-control concept meets

Laboratory

flight deck systems requirements. Also, the cab can provide the facility to conduct the architectural integration of the new display-control concept. As a system integration facility, the cab has become a concept demonstrator and the foundation for the development of an all-electronic cockpit of the 1990's.

The cab is supported by two Smiths Industries programmable symbol generators. Each can drive four hybrid stroke-raster displays - two primary and two repeaters. These were specifically designed to provide flexibility in a research environment. This flexibility includes driving different types of display heads (i.e., shadow mask, beam penetration, monochromatic display control (i.e., decrease speeds, refresh rates, line densities) and driving both line and arc raster. Software support includes a cross assembler and cross display compiler hosted on an HP3000 and PDPH/23 respectively. The cross compiler creates a data set that is interpreted by a general graphic program in the Smiths. The method used provides for much faster display build-up and change than has previously been done. The nature of the cross compiler permits display feature specification such as line, arc, text, and display objects in a way requiring little knowledge of programming. Displays can now be put together in hours instead of days.

These computers provide a wide variety of system interfaces (serial, parallel, DMA, etc.) to support intersystem communications. Other equipment include a Tektronix microprocessor development system, an Applied Science Laboratories eye view monitor, an IEC Voterm voice recognition system, a Texas Instruments voice recognition and synthesis system, numerous symbol generators, and a custom Collins graphics development system designed to work with 767/757 symbol generators. This Collins graphics development system, hosted on a VAX-11/750, is the forerunner of the CTS-2000 system proposed for use in the NASA Langley Experimental Avionics Systems Integration Laboratory (EASILY).

The all-electronic cab has the display features shown in Figure A.1-2. The modular consoles provide the flexibility to install and evaluate alternative instrument panel design concepts in both static and limited real-time dynamic modes. The current configuration includes: a left-side configuration of the 767/757 Electronic Flight Instrument System (EFIS); four additional color CRT displays to present airspeed, altitude, crew alerting, and other data and a

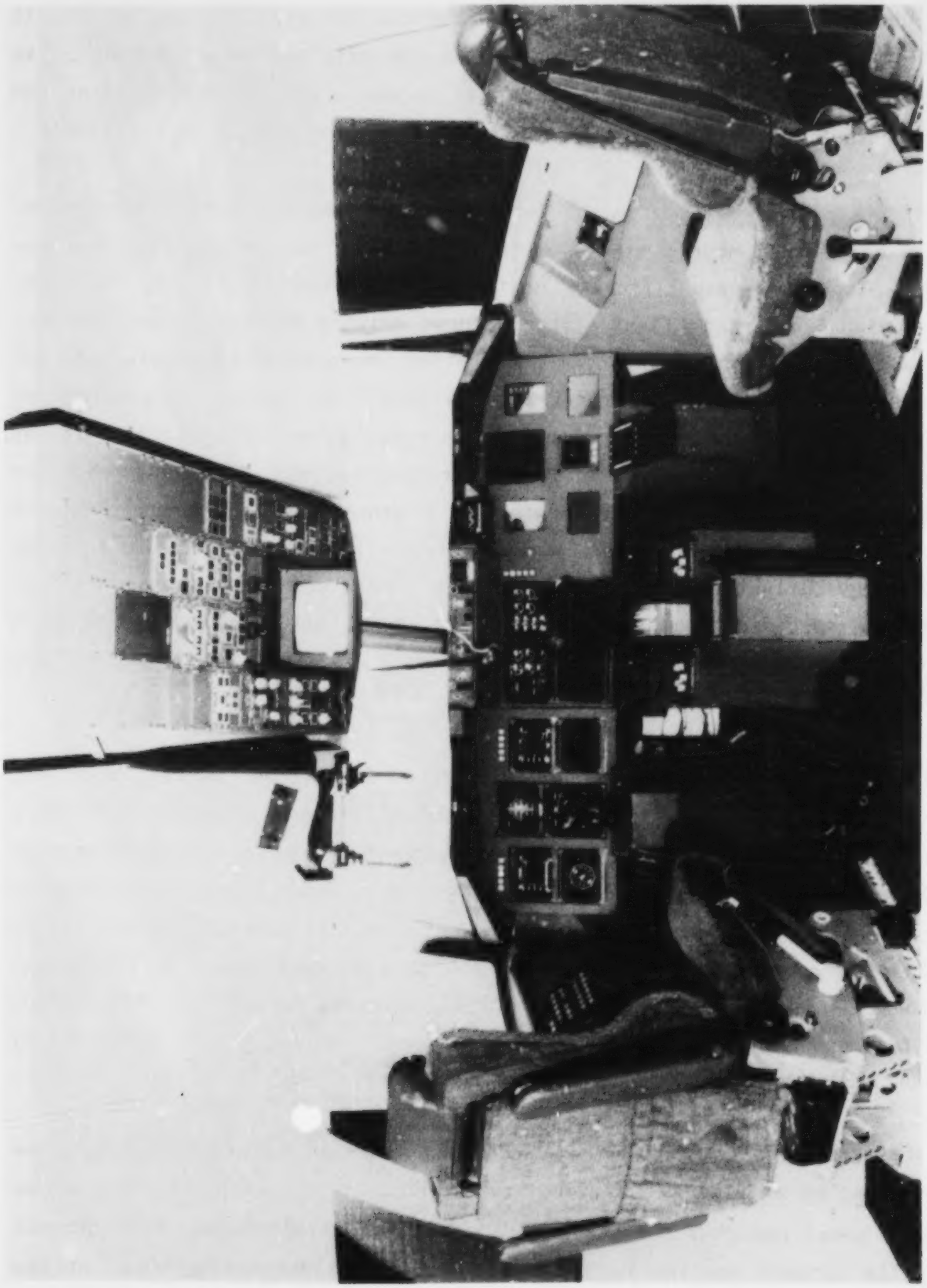


Figure A.1-2. All Electronic Flight Deck

holographic headup display (HUD) to present flight path information. The center instrument panel features: two Engine Indicating and Crew Alerting System (EICAS) color CRT displays, and a duplicate pair of CRT's located below them. The right-side is currently configured to accommodate a cross-section of alternative flat-panel thin film electroluminescent (TFEL) displays.

READEX FICHE

A.2.0 FSM SYSTEM DESCRIPTION

Figure A.2.0-1 shows a functional diagram of the FSM system. On the far right of the figure are the system-pilot interfaces, the display-control devices. On the bottom the airplane host simulator function components are shown. Between the FSM pilot interface are control units which execute the commands of the controller and control the display devices. They also modulate the pilot control actions affecting the monitor. Airplane related parameters are passed to the FSM via a single interface. This interface also acts as a path for data back to the the airplane simulation.

The FSM system consists of displays, controls, computers, and a mockup framework to provide demonstration and concept exploration within a transport-like cab. The system senses non-normal and imminent system problems and then provides guidance to the crew of alternative actions to handle the situation and provide different optional controls to effect these actions.

The system can be divided into two major hardware groups; those relating directly to sensing airplane abnormal status and providing information and suggested action to the crew; and those related to airplane simulation, flight controls, and primary displays.

A.2.1 Airplane Simulation, Control, and Flight Displays

The airplane simulation is for a large transport airplane and is hosted on a Data General S250 minicomputer with magnetic tape recording capability. The magnetic tape is the primary method of data collection for the FSM system.

Associated with the airplane simulation is a simulation console for initiating performance related failures and for other general simulation control functions such as "go to initial conditions" (IC), simulation hold, and simulation run. These same simulation control functions are provided in the cab area via an experimental control panel.

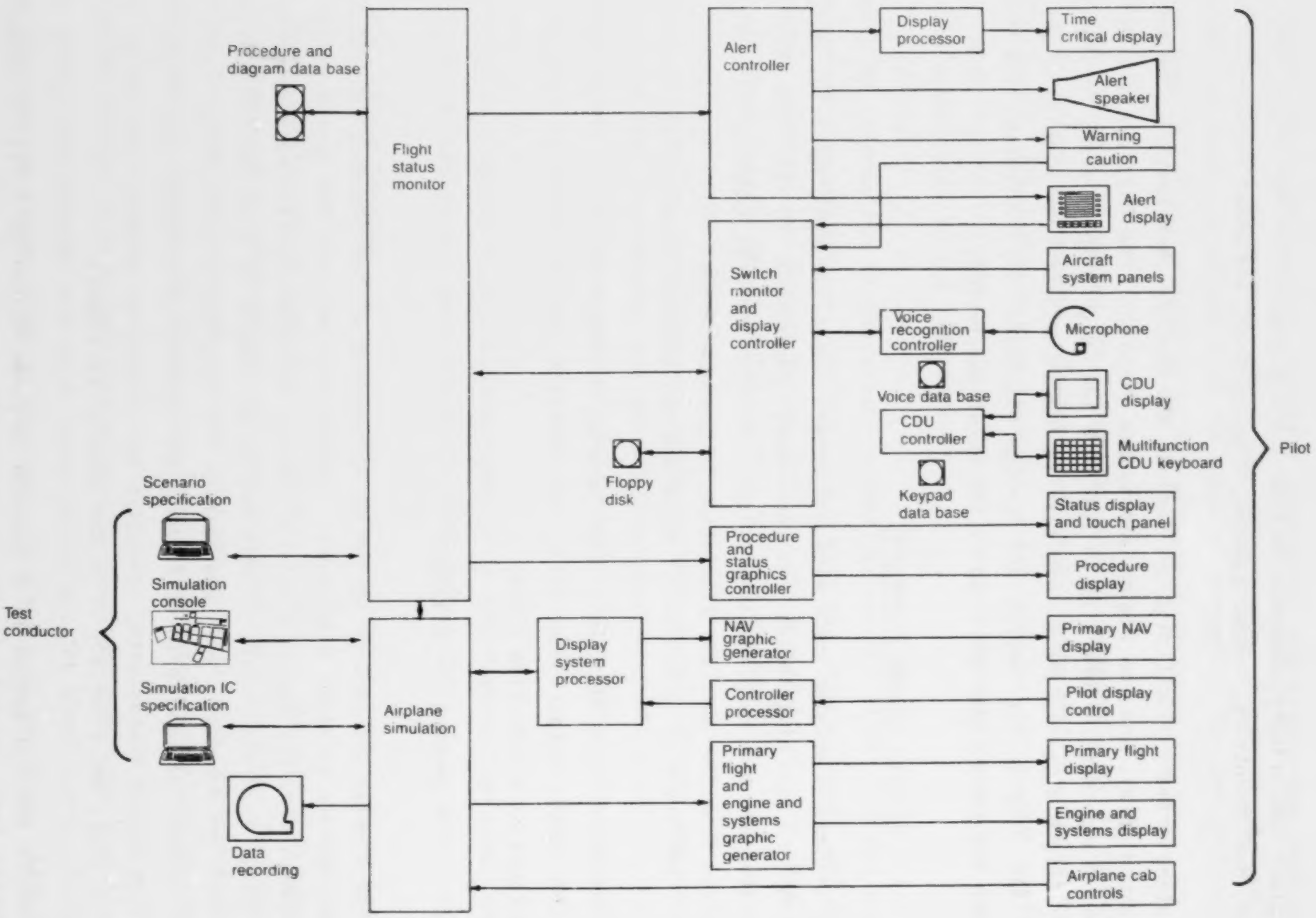

Procedure and diagram data base
Flight status monitor
Alert controller
Display processor
Time critical display
Alert speaker
Warning
caution
Alert display
Switch monitor and display controller
Aircraft system panels
Voice recognition controller
Microphone
Voice data base
CDU display
CDU controller
Multifunction CDU keyboard
Keypad data base
Floppy disk
Pilot
Scenario specification
Simulation console
Simulation IC specification
Test conductor
Procedure and status graphics controller
Status display and touch panel
Procedure display
Airplane simulation
Display system processor
NAV graphic generator
Primary NAV display
Controller processor
Pilot display control
Primary flight and engine and systems graphic generator
Primary flight display
Engine and systems display
Airplane cab controls
Data recording

Figure A.2.0-1. Flight Status Monitor Testing System Functional Layout

Airplane cab primary controls include a stick controller for pitch, roll, and trim, dual throttles, rudder paddles, flap control, and wheel retract.

Airplane primary flight displays include NAV display (horizontal), the primary flight display, and the engine and system display. The displays are Collins video shadow mask A-form size (4 3/4" X 4 1/4" high display area) for the primary flight display, and B-form size (4 3/4" X 5 3/4" high display area) for the NAV display and engine and system displays. All displays are hybrid stroke and raster with 256 line by 120 pixel resolution.

A.2.1.1 Display System Processor

This processor obtains reference parameters input through the pilot display controller and distributes the necessary parameters to the Nav Graphics Generator and the airplane simulation. It also performs computations on data received from the airplane simulation to produce results which are transmitted to the NAG Graphics Generator to drive the Nav Display dynamically.

The processor is a ROLM 1602 with paralle, 5 RS232 serial, a 11553A serial, and DMA input, output interfaces. It contains 32K bit words of memory. It also contains a real-time clock.

A.2.2 FSM Sensing and Displays

The FSM display and control system is independent of the research cab, so that it may operate in other simulators. Toward this end, the FSM system design is autonomous from the Boeing simulator, except for simulated-aircraft system status data. A direct result of this design philosophy is that the FSM must contain all the functions and capabilities for handling crew alerting; including alert categorization, prioritization, and inhibition schemes; algorithms for handling system status data; checklist and procedural schemes; display of aircraft status; and a variety of system control paradigms.

Central to the FSM system is a computer program hosted on PDP11/23 computer, this program senses system status, and degrading systems, directs display functions, prioritizes alerts, passes procedure and status data to the displays, and directs the alert data to the alert controler. The system then provides a number of displays to provide information of impending or current problems and provides guidance (procedures) as to ways of preparing for the problems or actual handling of the problem if it has already occurred.

Connected to the FSM system are integrated control components for pilot interaction to effect procedures. Control components integrated are the aircraft system panels, CDU multifunction keyboard, voice control, and a touch panel on the status display. These controls are collected by the switch monitor computer and transmitted to the FSM computer.

Display of information to the pilot is provided by the alert display, master warning and caution display, critical alert display, auditory sound and voice messages, airplane and system status display, and procedure display on either a color video display or the multifunction CDU LED display.

Control of alerting functions are primarily the master warning and caution switch and the line select and alerting function activation buttons on the alert display. The voice message is activated by a button on the control stick.

The PDP11/23 computer contains 256K memory. It has four (4) parallel input/output ports, two serial ports and a DMA input/output port.

A.2.2.1 Alert Display

The alert display is on the left in Figure A.2.2-1. The alert display or visual alphanumeric information display provides one location for warning caution and advisory messages. These messages provide some direction as to crew corrective actions and feedback to the crew when the faults are corrected.

The alert display is an A-form size color display shadow mask with 3" x 3" display area. The messages are color coded to reflect the alert level. The display provides for eleven lines of messages, 16 characters per line. Each line has associated with it a line select key to provide for an alert selection function. Alerting control functions are provided by six keys below the display (CHECKLIST, STATUS, STORE, RECALL, VOICE and PAGE).

A.2.2.2 Alert Speaker

An alert speaker is provided for alert tones and aural voice messages. The aural voice message is triggered by a push button on the control stick.

A.2.2.3 Master Warning and Caution Switch

A master warning and caution switch is mounted in front of the pilot on the glare shield (Figure A.2.2-1). The upper half of the switch is lighted red for warning and lower half in lighted amber for caution. The light and tones are cancelled by depressing the switch.

A.2.2.4 Time-Critical Display

The time-critical display is used to provide time-critical alerts with recommended action. It is mounted on the glareshield to the right of the master warning and caution switch. The time-critical display is a Litton Systems Canada Limited multicolor LED display. The display area is 3 1/4" X 2 1/4" with a resolution of 32 pixels per inch. Each pixel can be either red, green, or amber (combined red and green) and can be intensity controlled.

A.2.2.5 Procedure Display

The procedure display is either a color shadow mask video to the right of the alert display (Figure A.2.2-1) or the multifunction CDU LED display at the upper left corner of the center stand. Video display is a Collins B-form size color video display (4 3/4" X 5 3/4" display area). The Collins hybrid (both stroke and raster) display provides for color coding of the procedure checklist features. The Collins resolution is 256 line by 120 pixel resolution. The video is driven from a Smith's Symbol Generator using a procedure checklist downloaded from the FSM computer. The control display unit (CDU) display, a Litton Systems Canada Limited multi mode matrix green monocromatic LED flat panel display. The LED display area is 4" high by 3" wide with 64 pixel/inch resolution.

A.2.2.6 Status Display

The status display is located below the procedure display (Figure A.2.2-1). The display is used to provide airplane status, procedure checklist subsystem diagrams, failed system diagrams, and failed system information. The touch panel provides a means for interacting with the display to effect system control functions. The touch panel surface provides for touch discrimination of up to ten across and twelve down. The display is a Collins B-form size (4 3/4" X 5 3/4" high display area) color video display with a touch panel clear plastic sheet over the surface of the display. The display is a 256-line by 120-pixel resolution hybrid (both stroke and raster) display.

A.2.2.7 Multifunction Keyboard

The multifunction keyboard is part of the CDU which is mounted before the CDU scratch pad in the upper left corner of the center stand. These switches are used for working procedure checklists indicating to the FSM the pilot desired action for each checklist item. The keyboard is a matrix of switches (three across by five down) developed by Honeywell Micro Switch Division. The switches are solid-state Hall effect momentary action with tactile feedback. Each switch face is a 0.4" high by 0.875" wide sunlight readable green LED display with 40 pixel/inch resolution. The switch changes its function dynamically. Two character sizes, 5 x 7 pixel and 10 x 14 pixel, provide for feedback to the pilot of the switch's current function.

A.2.2.8 Voice Control

Voice control is provided via a Texas Instruments TM320 Microprocessor Speech Synthesis and Recognition System. The system recognizes a connected stream of words for activating alerting functions and as system controls through the procedure checklists. Depressing a button on the control stick opens the recognition system for listening and the bottom line on the CDU display provides for feedback on what the recognition system understood. Activation is followed by a verbal "GO".

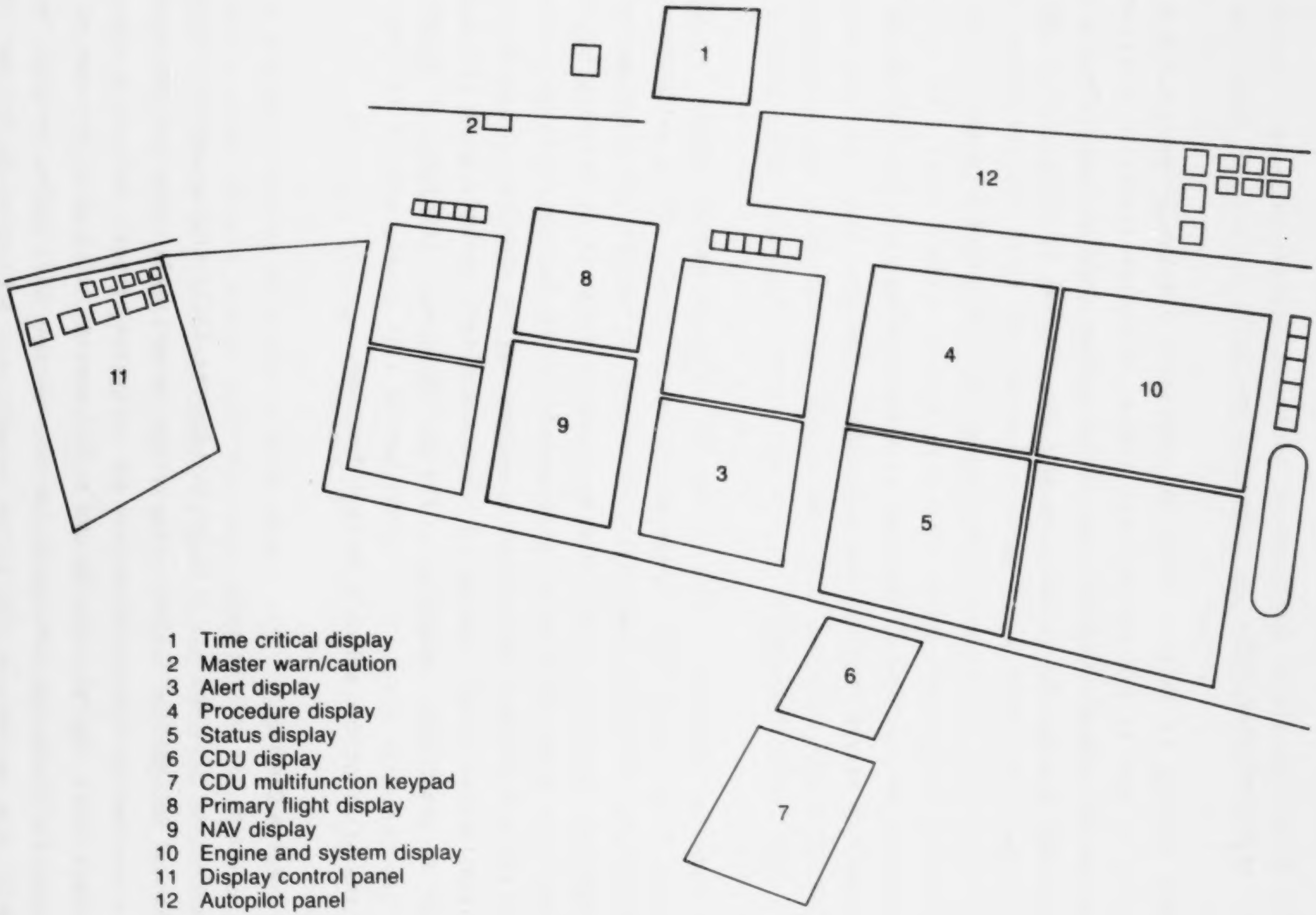

1
2
12
8
4
10
11
9
3
5
6
7
1 Time critical display
2 Master warn/caution
3 Alert display
4 Procedure display
5 Status display
6 CDU display
7 CDU multifunction keypad
8 Primary flight display
9 NAV display
10 Engine and system display
11 Display control panel
12 Autopilot panel

Figure A.2.2-1. Displays Layout

This system combines the two basic components of speech technology, speech synthesis and recognition, into a single unit. The speech synthesis is based on the TM 320 microprocessor and uses a linear predictive coding algorithm to model the human voice. It uses a data rate of 2400 bits per second of speech and a high density information compression to store 16 minutes of speech on an 8-inch floppy disk.

The voice recognition component is speaker dependent (i.e., must be trained for each user. It recognizes connected streams of words allowing the pilot to use normal sentences to issue commands. Computer recognition accuracy of connected word phrases is typically greater than 99% with the proper training regime.

A.2.2.9 Touch Panel

A touch interactive display panel was used as the control device for the "touch panel" concept.

The touch panel is a thin plastic sheet across the face of the status display (4.5" x 5.5"). The panel is able to discriminate 12 rows vertical by 10 columns horizontal. An electronic scanner polls the sheet 20 times a second to touch depression and transmits the depression to the switch monitor.

A.2.10 Alert Controller

The Alert Controller was built by Boeing to act as a general purpose aircraft simulator alert controller and driver. It uses two Z80 microprocessors to control alert events, monitor switch actions, generate alert tones and voice messages and output data to other systems such as the alert display and the time critical alert display.

The voice alerts were generated by a Boeing refined voice encoder/decoder board. This voice system uses 2000 bytes of memory per second of speech and produces a high quality reproduction of voice patterns it records. Two voice message data bases were stored on EPROM.

APPENDIX B

FLIGHT STATUS MONITOR
TRAINING MANUAL

1.0 INTRODUCTION

Over the past 11 years, the Federal Aviation Administration has sponsored the investigation and development of systems to alert and inform the crew about non-normal aircraft situations. The scope of the successive programs has increased so that system complexity has progressed from a consideration of a single alert situation, the independant altitude monitor or ground proximity alert, to a consideration of the total aircraft status. The results of this progression is that a highly self-contained and complex system has been identified that will facilitate crew responses to alerting situations. This system is known as the Flight Status Monitor (FSM), and its functions include: informing the crew that a non-normal situation has (or possibly will in the near future) occurred; identifying the problem to the crew; indicating the urgency of the situation; providing the crew with guidance for responding to the problem; and providing feedback to the crew concerning the adequacy of their response.

This manual is to be used as part of the training and familiarization program for pilots participating in the Phase II FSM testing. It provides the crews, and any observers, the background information necessary to understand and use the candidate FSM display/control concepts. The document is divided into four major sections. The first section provides an introduction and some background for the FSM. The second section describes the alerting components of the FSM which include: the master alerts, both aural and visual; the visual information or alert display; and the voice alert display. The third section describes the guidance and feedback components. There are five candidate display/control concepts for these components, and the operating procedures for each will be covered. The last section will describe the evaluation in which you will be participating.

The FSM is a system which not only consolidates and standardizes the crew alerting function, but also has the capability of monitoring the array of aircraft sensors, combining and interpreting the information, and providing the crew with guidance in responding to non-normal situations, and feedback about the adequacy of their response and an indication of the status of their aircraft. The logic within the system provides capabilities such as: adapting to changing flight phases; prioritizing alerts; integrating procedures; translating operational and mechanical abnormal conditions into aircraft status information; and applying historical data to provide predictive information.

The system provides the crew with a number of different types of information. The alerting components of the system attract the crew's attention to the non-normal situation, identify the specific problem or problems, and indicate of the urgency of the situation. The guidance component of the system contains the information that the crew requires to respond to the situation. The action steps for situations resulting from simultaneous problems will be integrated to provide the crew with a systematic response or action flow. This component also provides an indication as the crew completes each action item in the procedure. Finally, the feedback component supplies aircraft-level and system-level status information. The system is also capable of supplying the supplemental information that would normally be found in the Operations Manual.

2.0 ALERTING COMPONENTS

The crew will be alerted to problems in three urgency categories: warning, caution and advisory. For the FSM these categories are defined as follows:

Warning -	Any non-normal operational or aircraft system conditions that require immediate corrective or compensatory crew action.
Caution -	Any non-normal operational or aircraft system conditions that require immediate crew awareness and prompt corrective or compensatory crew action.
Advisory -	Non-normal operational or aircraft system conditions that require crew awareness and may require crew action.

There are several alerting components included in the FSM system. The master visual alert will be used to get your attention (visually) for warnings (red) and cautions (amber). It is located on the glareshield above the primary flight instruments. Associated with the master/visual display is a master aural alert which consists of a different sound for each urgency level: European siren for warnings; steady sound for caution, and a chime for advisories. Both the visual and aural master alerts can be cancelled by depressing the master warning/caution switch.

Simultaneously with the master alert you will get an alphanumeric message, i.e., "L ENG ANTI-ICE", on your alert display (Figure 1). This message will identify the problem and be color coded to indicate urgency. Figure 2 provides a close-up of the alert display. The display has active lines for eleven alert messages, one per line. If there are more than eleven alerts or if any alerts have been stored into the system memory, the bottom line of the display will be used to indicate the number of alerts stored (e.g., M4) or the number of pages of alerts (e.g., 1/2, 2/2). Alerts will be grouped on the display according to their urgency-level with warnings higher than cautions which are in turn above advisories. The line select keys located on both sides of the display permit you to indicate specific alert(s) to the system and subsequently take some action on that specific alert. These keys corres-

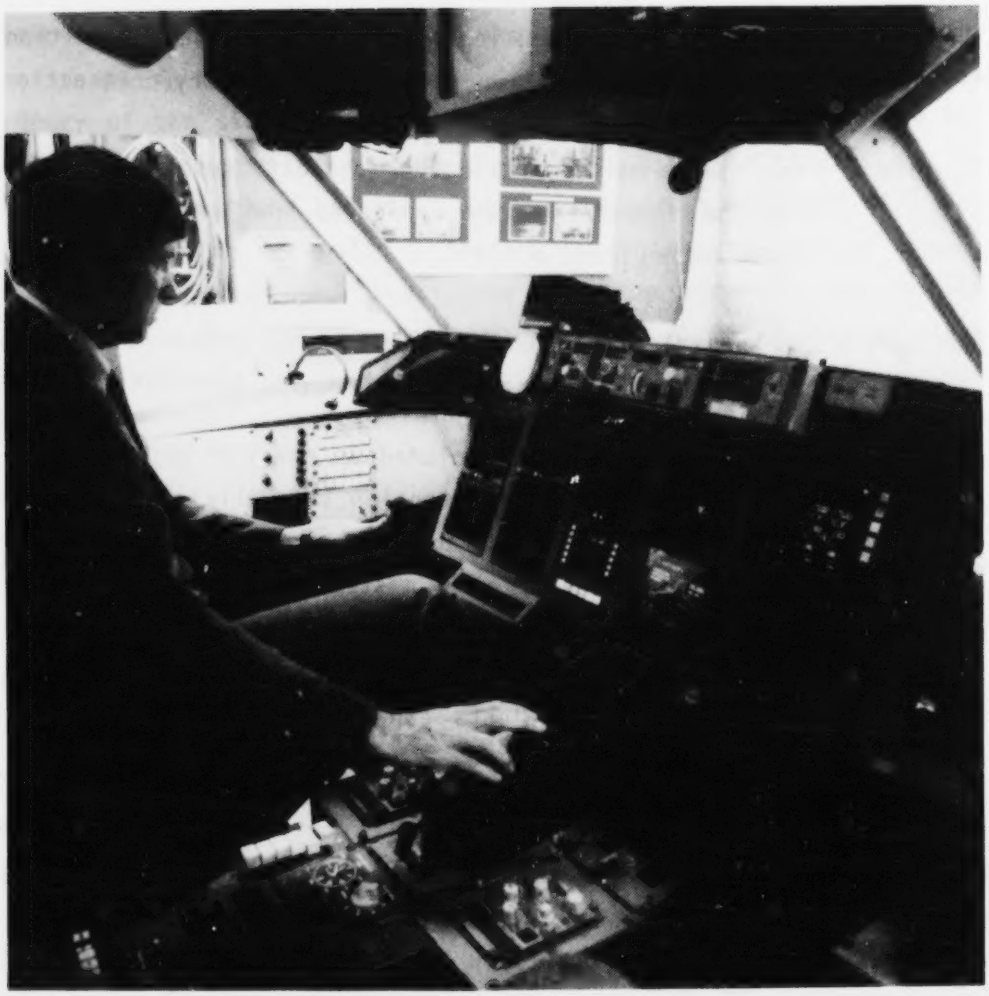


Figure 1. Flight Status Monitor Displays

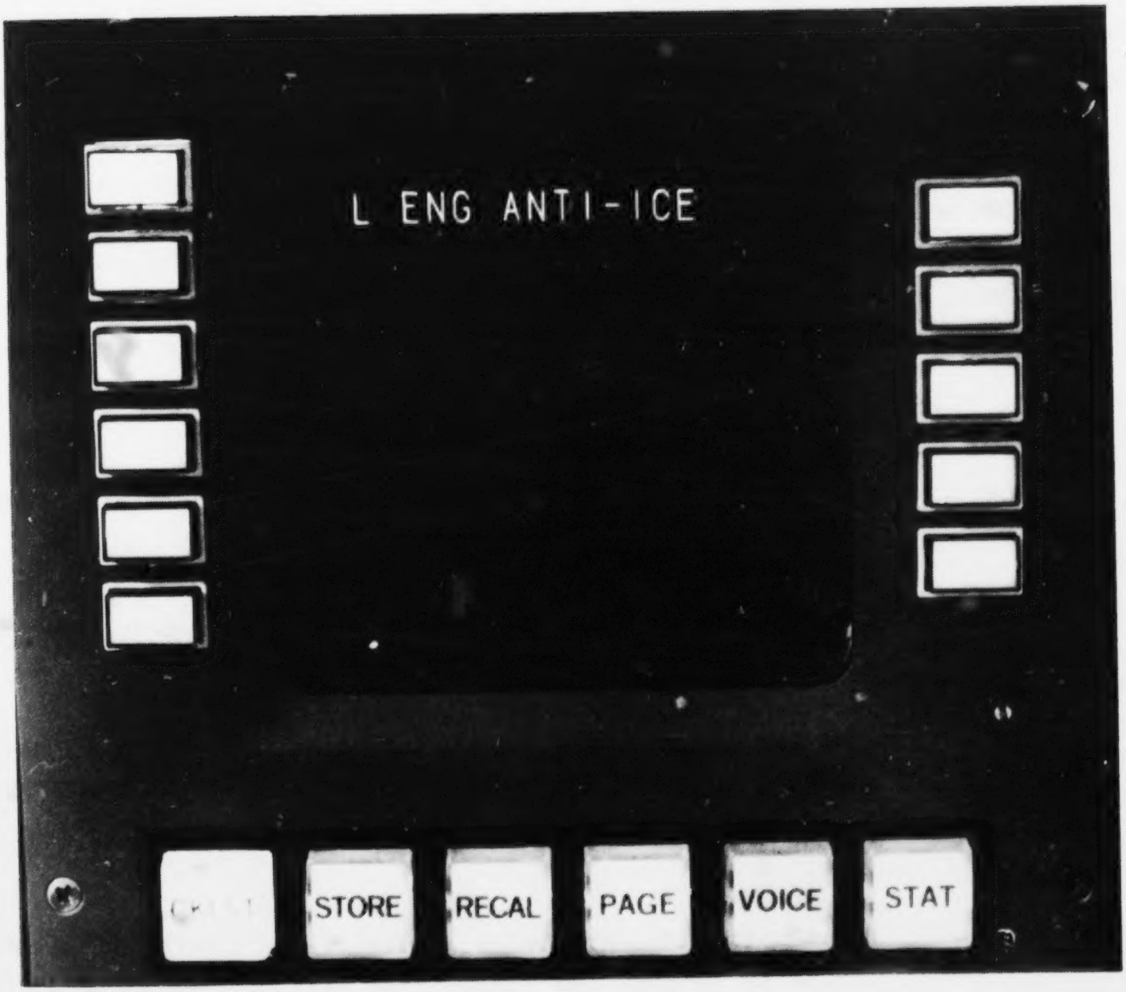

L ENG ANTI-ICE
STORE
RECAL
PAGE
VOICE
STAT

Figure 2. The Alert Display With FSM Controls

pond to the lines of the display with the top key on the left indicating line one and the top key on the right line two. The second key on the left is for line 3 and the second on the right for line 4, etc.. The control keys below the displays actuate the following system functions:

CKLST - Controls the paging function of the checklist, multiple pushes of the key will result in paging the procedures display for checklists which are too long for one page.

STORE - Stores alert messages into the system memory. Messages may be stored individually by using the line select function and the "STORE" key, or all storable alerts can be put in memory by using the "STORE" key without selecting any alert; only alerts which have no incompleted checklist items may be stored and warning messages cannot be stored.

RECAL - Recalls all the alert messages from memory and displays them on the screen with the cautions below any warnings and the advisories below the cautions; the messages will also be chronological within urgency level with the most recent alert on top.

PAGE - This key controls only the alert display; when there are more alerts than can be accommodated on the display the "PAGE" key advances the display through the available alerts a page at a time.

VOICE - One of the concepts being evaluated is controling system action by voice. The "VOICE" key will be used to activate the voice control components during that evaluation only.

STAT - Calls up and activates the status display. The first push of the "STATUS" key will result in aircraft-level status being displayed. If there is (are) an alert(s) selected, the second key push will result in the presentation of the series of systems being reconfigured during the response to the alert, the third (and subsequent) activation(s) will provide the system status of the faulted system(s). After displaying all the faulted systems another key push will result in calling up any supplemental information available about the alert.

The final alerting component is the voice display. For warning-level alerts that are time-critical (e.g., ground prox), the voice alert will be presented automatically. To cancel the automatic voice presentation you depress the master warning/caution switch; the visual time-critical message will remain. Other warnings and cautions will have the voice alert available to you by depressing the thumb switch on the control stick. The voice alerts will be identical to the message presented on the alert display. The optional warning and caution voice messages will be presented only once with each thumb switch depression.

3.0 GUIDANCE AND FEEDBACK COMPONENTS

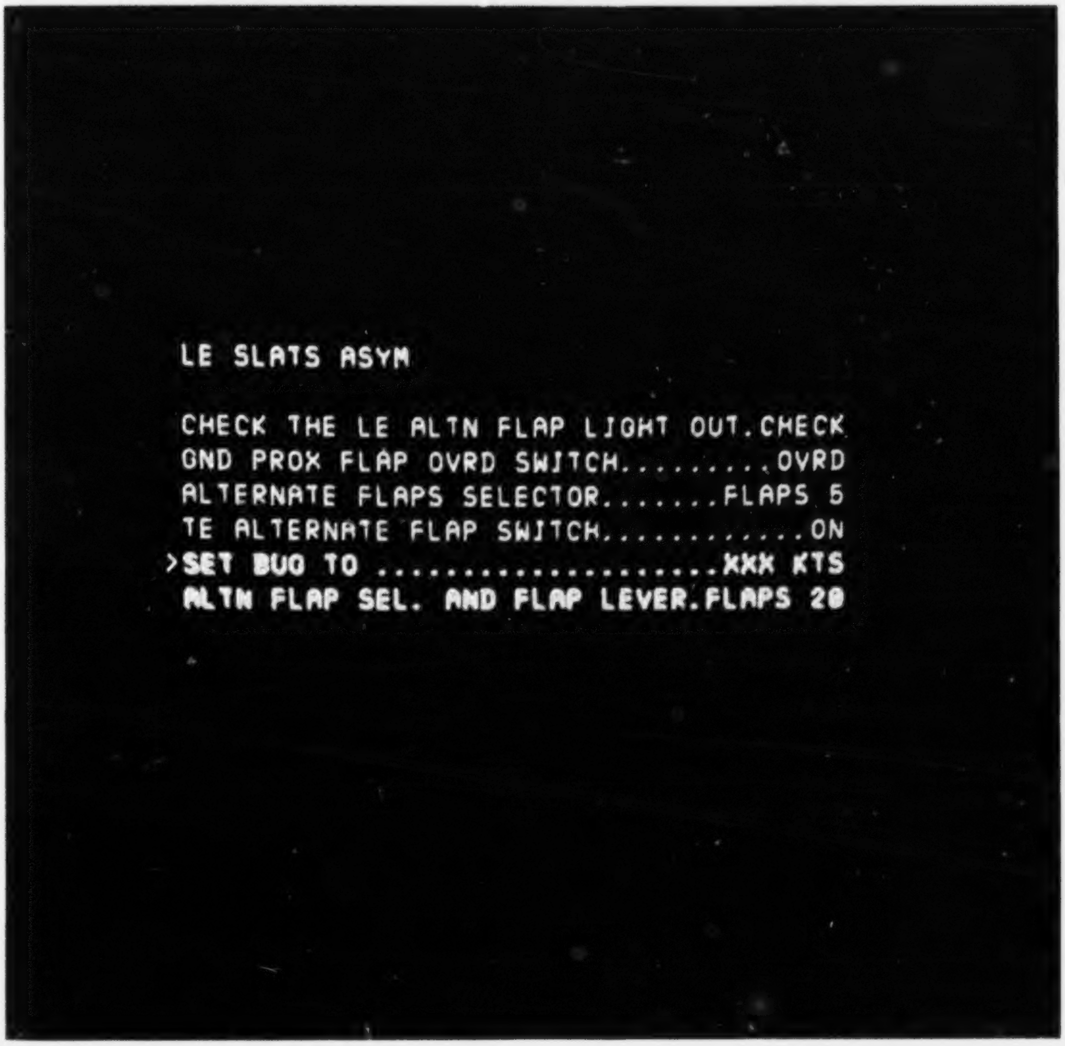
The candidate FSM display/control concepts differ only in the guidance and feedback components. The concepts differ in their level of automation: manual, system aided and automatic. With the manual method, aircraft system reconfiguration is accomplished on the systems overhead panel. The system aided concepts have automatic display callup, and the aircraft systems are controlled by innovative concepts in conjunction with the FSM displays including voice interaction, touch panel overlays, and a multifunction keyboard. The last concept is automatic reconfiguration which only requires the crew to give a go-ahead signal. This concept may be used in conjunction with any of the above concepts, but for this study it was implemented only in the multifunction keyboard concept. In all of the concepts, feedback information is provided on both the procedures and status displays.

The major FSM display components used to provide the guidance and feedback function are the procedures display and the status display. The crew will interact with both of these displays while responding to the alert situations.

Procedures Display

Step-by-step procedures for responding to normal and non-normal situations are presented on the procedures display in checklist format (Figure 3). One action item is presented per line whenever feasible, and as many action items as feasible are presented on a single page. The items requiring crew action are one color, and the completed actions are another color. As the crew completes an action, the action item changes color. If the action is not sensed by the aircraft, the crew must acknowledge its completion, by selecting a "DONE" key, before the item changes color (Figure 4). If the crew fails to perform an action item and proceeds to the next action item, the uncompleted item will remain in the action color.

The actions will be listed in priority order. All actions that have an immediate effect on aircraft safety will be listed first. Lesser procedures and procedures affecting other flight phases will follow. The latter will automatically be integrated into checklists in those flight phases. For multiple alerts, the actions will be integrated according to the priority logic established by the system.



```
 LE SLATS ASYM

 CHECK THE LE ALTN FLAP LIGHT OUT.CHECK
 GND PROX FLAP OVRD SWITCH.........OVRD
 ALTERNATE FLAPS SELECTOR.......FLAPS 5
 TE ALTERNATE FLAP SWITCH............ON
>SET BUG TO ....................XXX KTS
 ALTN FLAP SEL. AND FLAP LEVER.FLAPS 20
```

Figure 3. Leading Edge Slats Asymmetry Alert Procedures

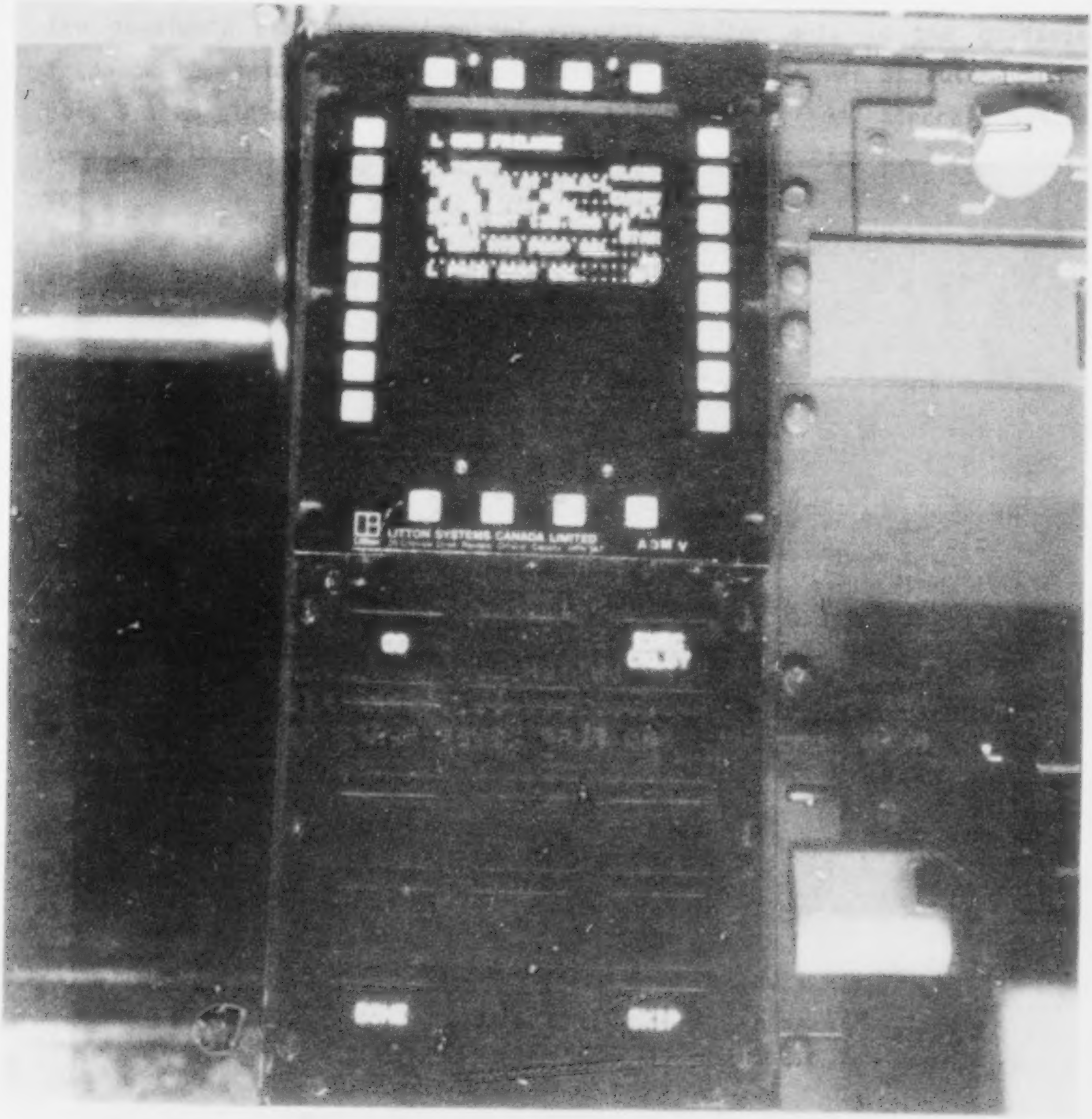

LITTON SYSTEMS CANADA LIMITED
DONE
SKIP

Figure 4. System Action Panel

Status Display

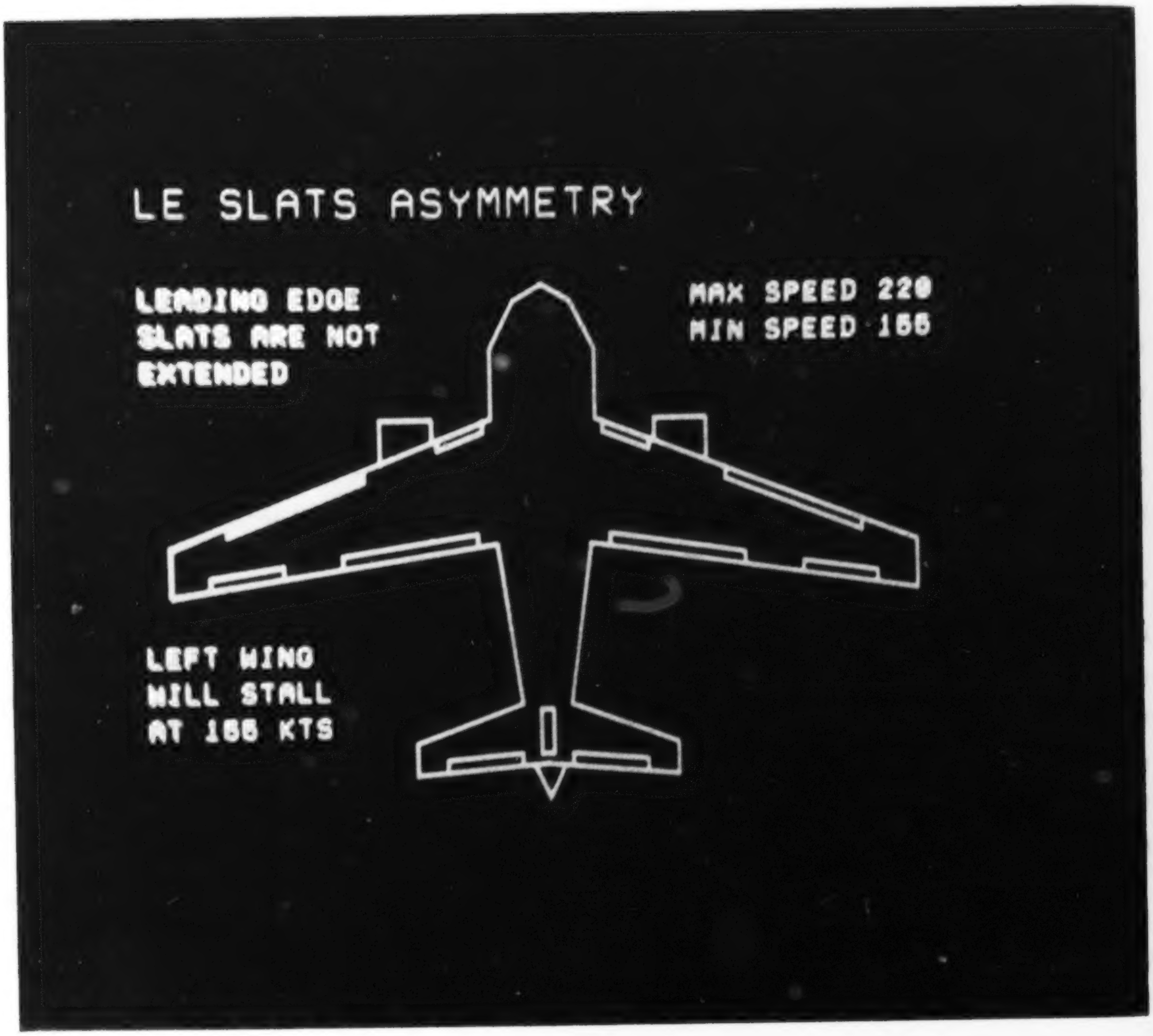
The status display will have pictorial and alphanumeric presentations. There may be as many as four presentations associated with a fault:

1. A page presenting the aircraft status; degraded flight control systems, operational limits and the non-operating systems (Figure 5).
2. A page(s) showing a schematic diagram of the system(s) involved with the procedural action(s) (Figure 6).
3. A page(s) identifying a system with the primary failure (Figure 6).
4. A page(s) presenting any additional, operational information that is currently contained in operations and flight manuals (Figure 7).

The first status page will show aircraft status, including degraded flight control systems and operating limits. The second page (or set of pages) will display a diagram of the procedural action site(s). The third page will show a diagram of the system or subsystem containing the failure which generated the alert. The fourth page (or set of pages) will display information pertinent to the flight operations as a result of the failure/ alerting situation.

System status will be shown by simplified system schematics. These schematics will show the system by interconnecting lines and identify different components by symbol shapes. Color coding will be used to indicate operating and fault status. For example, white symbols could indicate "OFF" status and a green symbol could indicate "ON" status. Alphanumerics will be used to identify the components and for presenting quantitative parameter values when required.

Aircraft status will be shown by a simplified pictorial of an aircraft (e.g., a plan view outline of the aircraft). Symbols will be used as much as possible for the faulted flight control systems. Other information will be presented by alphanumerics. Failed components will be color coded according to fault level (e.g., red or amber).



LE SLATS ASYMMETRY

LEADING EDGE
SLATS ARE NOT
EXTENDED

MAX SPEED 220
MIN SPEED 166

LEFT WING
WILL STALL
AT 166 KTS

Figure 5. Aircraft Status Display

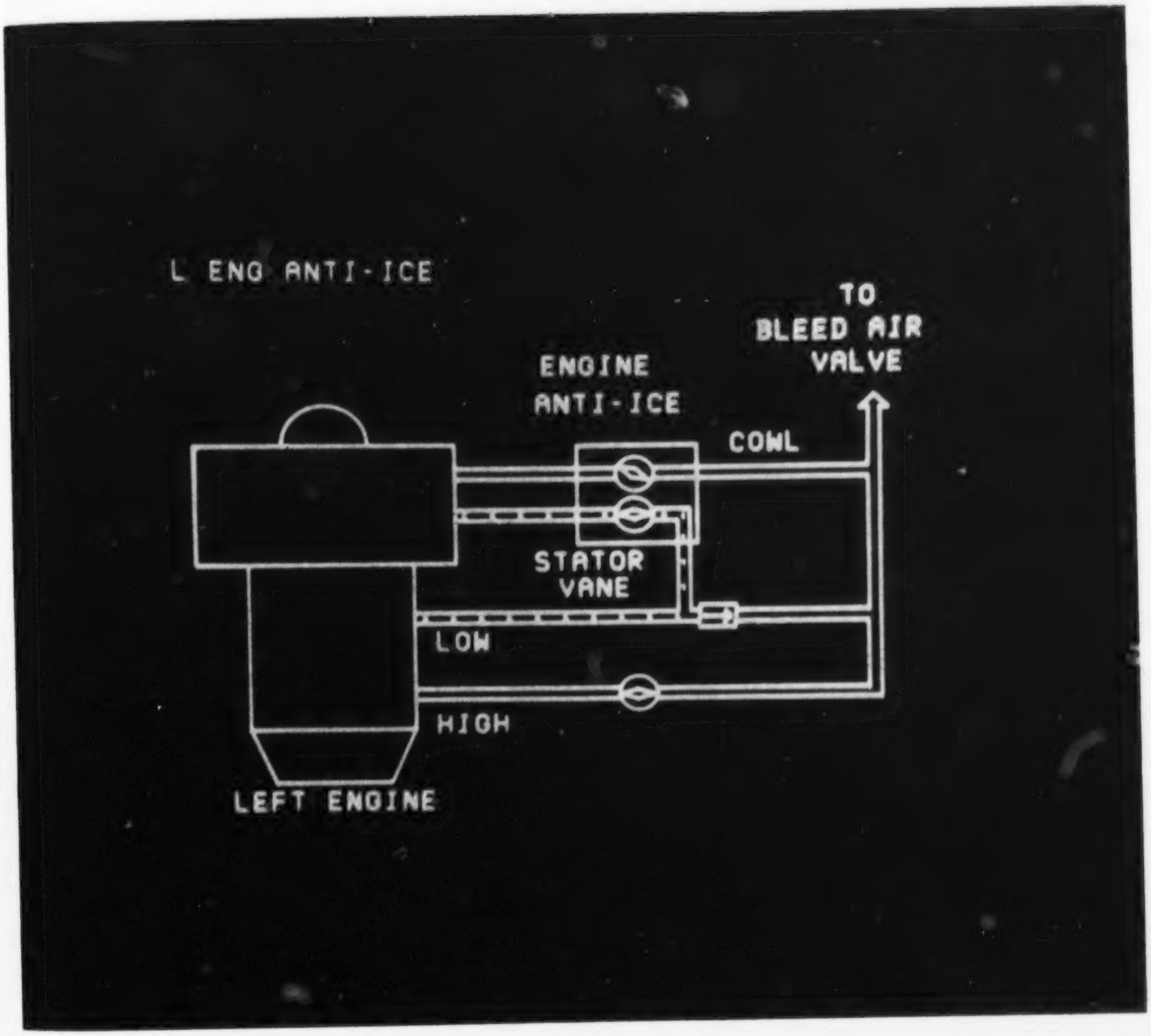
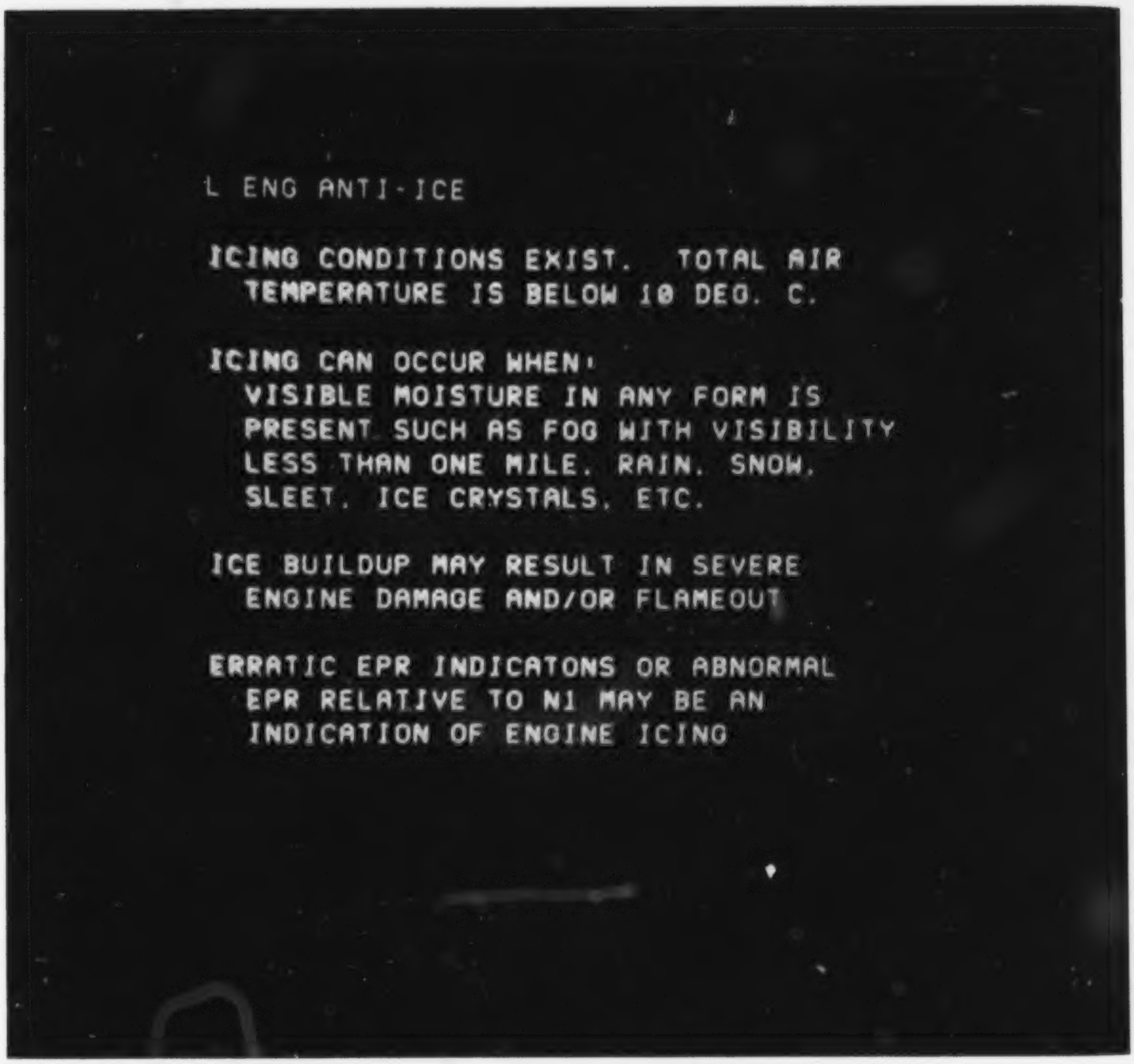

L ENG ANTI-ICE
TO
BLEED AIR
VALVE
ENGINE
ANTI-ICE
COWL
STATOR
VANE
LOW
HIGH
LEFT ENGINE

Figure 6. Engine Anti-Ice System Diagram



```
L ENG ANTI-ICE

ICING CONDITIONS EXIST.  TOTAL AIR
  TEMPERATURE IS BELOW 10 DEG. C.

ICING CAN OCCUR WHEN:
  VISIBLE MOISTURE IN ANY FORM IS
  PRESENT SUCH AS FOG WITH VISIBILITY
  LESS THAN ONE MILE, RAIN, SNOW,
  SLEET, ICE CRYSTALS, ETC.

ICE BUILDUP MAY RESULT IN SEVERE
  ENGINE DAMAGE AND/OR FLAMEOUT

ERRATIC EPR INDICATONS OR ABNORMAL
  EPR RELATIVE TO N1 MAY BE AN
  INDICATION OF ENGINE ICING
```

Figure 7. Engine Anti-Ice Operational Information

System Control

Several alternatives have been selected for control of the aircraft systems (e.g., hydraulics, electrical, FCS, fuel, etc.) in conjunction with the FSM. These include:

1. System Control Panels - System control panels are located in the overhead panel. The aircraft systems are controlled with the systems panel which is not part of the FSM. However, information feedback on the status of the controls and the operation of the system is provided by the FSM.
2. Touch Panel Control - The touch panel overlaying the status display allows system control to be next to the displayed procedures. The touch panel allows the crew to perform the action item by touching the display. Feedback information is presented on both the procedures and status displays, and the crew's attention is focused on only these two displays for completing the procedure.
3. Voice Interactive Control - Voice commands are used to call up and control the displays and the aircraft systems. The voice system is activated by depressing the FSM VOICE key. After activation, the crew is able to call up and perform the action items.
4. Multifunction Keyboard - The multifunction keyboard is configured with programmable legend keys. The first key lists the first action item from the procedures display. The second action item is listed on the second multifunction key, and so on. To perform the action item all the pilot has to do is depress the corresponding multifunction key (Figure 8).

The following paragraphs will describe each of the concepts and its associated functions and operation.

Basic Concept

The operation of the Basic concept is shown in Figure 9. After an alert occurs, the crew cancels the master caution and warning indicator and reads the alert display to identify the fault. By pushing the line select key, the alert procedure is displayed on the procedures display and the aircraft status is presented on the status display. By repeated pushing of the CHECKLIST key, the crew may step through the procedure pages. By selecting the STATUS key, the FSM will display the system schematic associated with the first procedural action item.

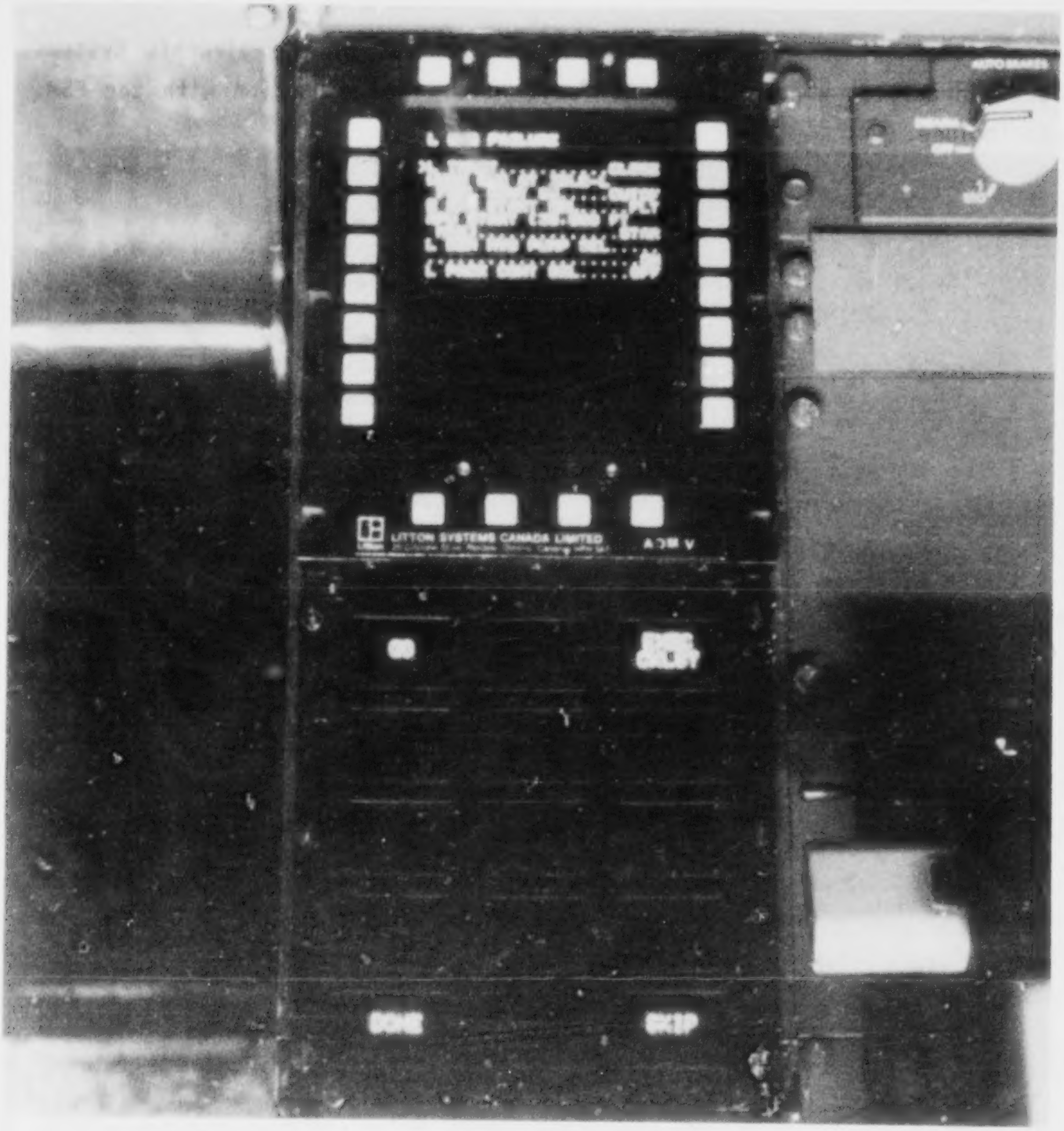

LITTON SYSTEMS CANADA LIMITED
GO
DONE
SKIP

Figure 8. System Action Panel

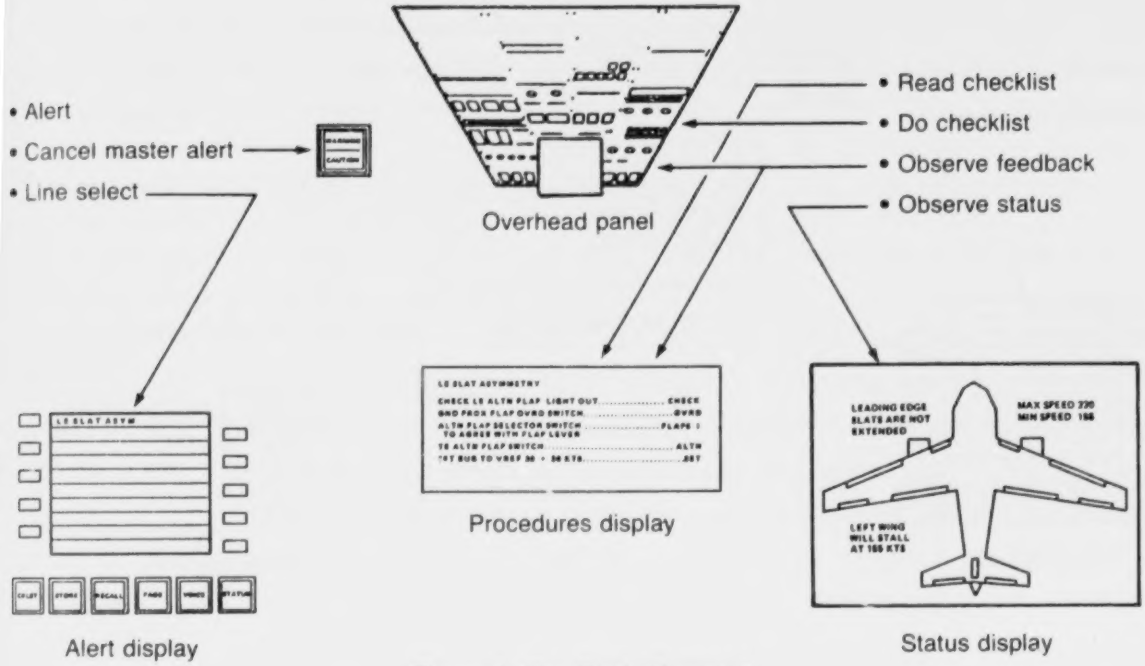
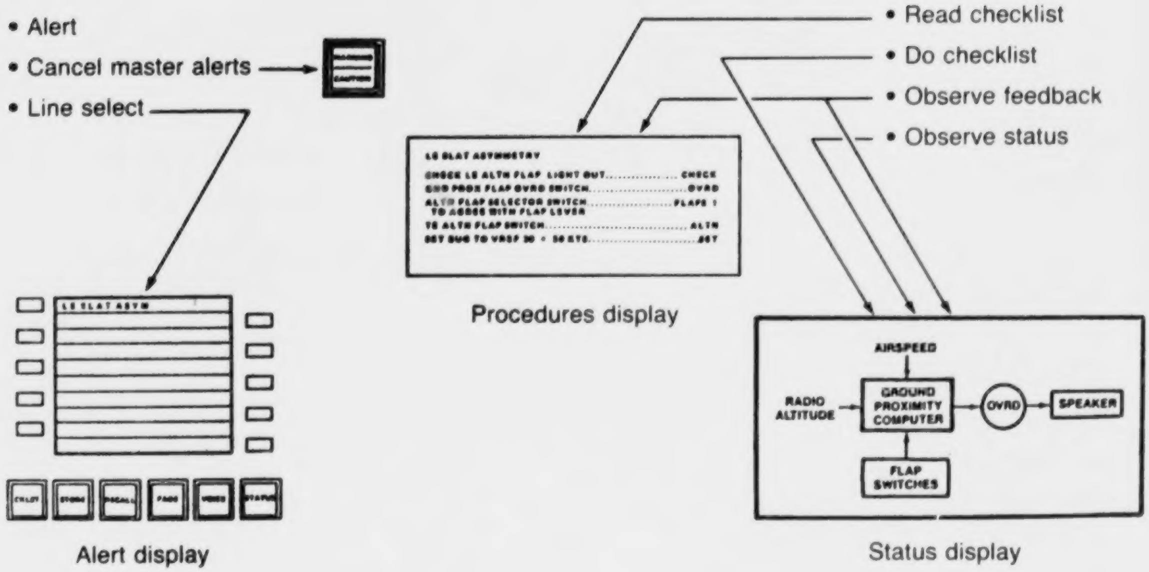

• Alert
• Cancel master alert
• Line select
WARNING
CAUTION
LE SLAT ASYM
CKLST
STORE
RECALL
PAGE
VIDEO
STATUS
Alert display
Overhead panel
• Read checklist
• Do checklist
• Observe feedback
• Observe status
LE SLAT ASYMMETRY
CHECK LE ALTN FLAP LIGHT OUT .... CHECK
GND PROX FLAP OVRD SWITCH .... OVRD
ALTN FLAP SELECTOR SWITCH TO AGREE WITH FLAP LEVER .... FLAPS 1
TE ALTN FLAP SWITCH .... ALTN
SET BUG TO VREF 30 + 30 KTS .... SET
Procedures display
LEADING EDGE SLATS ARE NOT EXTENDED
MAX SPEED 220
MIN SPEED 155
LEFT WING WILL STALL AT 155 KTS
Status display

Figure 9. The Basic Concept


• Alert
• Cancel master alerts
CAUTION
• Line select
LE SLAT ASYM
STORE
RECALL
PAGE
VIDEO
STATUS
• Read checklist
• Do checklist
• Observe feedback
• Observe status
LE SLAT ASYMMETRY
CHECK LE ALTN FLAP LIGHT OUT .... CHECK
GND PROX FLAP OVRD SWITCH .... OVRD
ALTN FLAP SELECTOR SWITCH .... FLAPS 1
TO AGREE WITH FLAP LEVER
TE ALTN FLAP SWITCH .... ALTN
SET BUG TO VREF 30 + 30 KTS .... SET
AIRSPEED
RADIO ALTITUDE
GROUND PROXIMITY COMPUTER
OVRD
SPEAKER
FLAP SWITCHES

Alert display

Procedures display

Status display

Figure 10. The Touch Panel Interactive Display Concept

The crew reads the checklist and performs the necessary actions on the overhead panel. If there is more than one page of procedures, the completion of the items on the first page will bring up the next page. After the procedures are completed, the crew may step through the status pages by pushing the STATUS key. After completion of the checklist procedures, the displays will be cleared. The alert message is removed from the alert display if the alerting situation no longer exists; otherwise, it may be cleared by line selecting the alert and selecting STORE. Selecting STORE without a line selected will store all alerts, except warning level alerts and alerts which have pending checklists.

Touch Panel Interactive Concept

This concept is illustrated in Figure 10. The procedures display and status display (aircraft status page) are automatically called up by the pilot selecting the line address key on the alert display. The pilot performs the actions directly on the status display. After manually stepping past the aircraft status page, the status display will contain a schematic, related to the first action-item, with computer generated touch keys to reconfigure the system. Feedback information is presented on both the procedures and status displays. Each action item will have a corresponding schematic diagram on the status display. This display is also touch interactive for calling up more detailed information.

Voice Interactive Concept

This concept, shown in Figure 11 uses voice for both messages and control of the displays and aircraft systems. Voice control activation is optional, and both the displays and systems may be manually controlled as described under the Basic or Touch Interactive concepts. Voice messages are used to direct the crew's attention to alerts and to the actions to be performed if the alert is a time-critical alert.

After pushing the line select key, the pilot may select voice interaction by depressing the VOICE key. When the displays are called up, the first action item would be addressed. To execute an action item, the crew says, for example, "PUMP 1 OFF", the system will display what has been said on the single-line display directly in front of the pilot (below the EHSI). If the display is correct, the pilot gives an execution command, "GO" and the system will

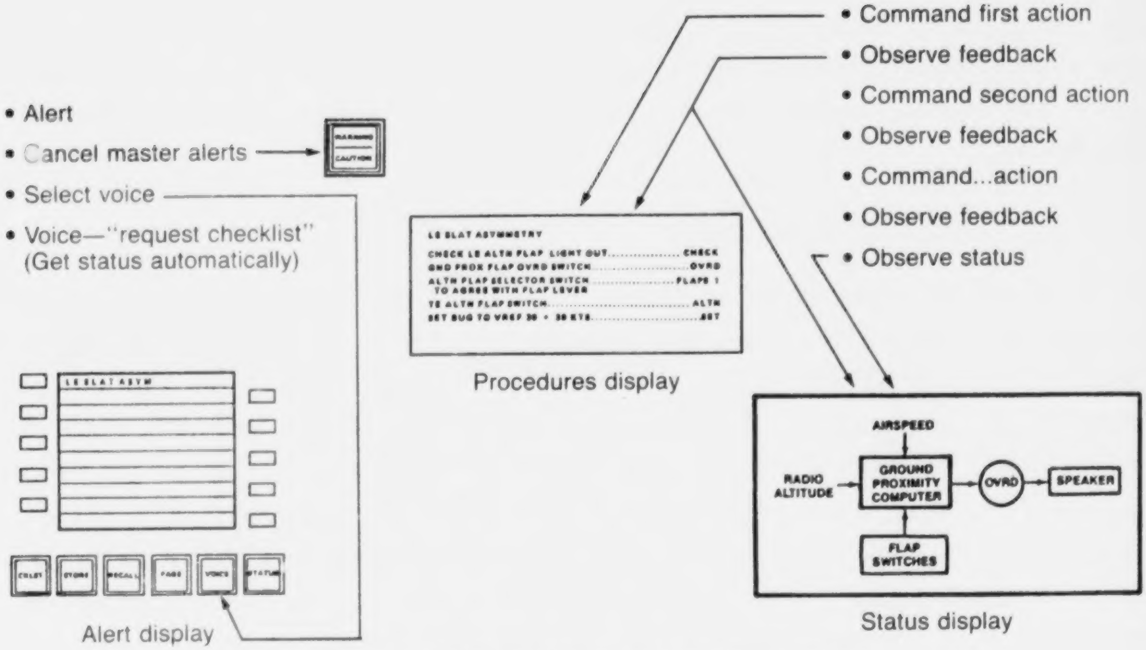

• Alert
• Cancel master alerts
WARNING
CAUTION
• Select voice
• Voice—"request checklist" (Get status automatically)
LE SLAT ASYM
STORE
RECALL
PAGE
VOICE
STATUS
Alert display
• Command first action
• Observe feedback
• Command second action
• Observe feedback
• Command...action
• Observe feedback
• Observe status
LE SLAT ASYMMETRY
CHECK LE ALTN FLAP LIGHT OUT.................CHECK
GND PROX FLAP OVRD SWITCH.................OVRD
ALTN FLAP SELECTOR SWITCH TO AGREE WITH FLAP LEVER.................FLAPS 1
TE ALTN FLAP SWITCH.................ALTN
SET BUG TO VREF 30 + 30 KTS.................SET
Procedures display
AIRSPEED
RADIO ALTITUDE
GROUND PROXIMITY COMPUTER
OVRD
SPEAKER
FLAP SWITCHES
Status display

Figure 11. The Voice Interactive Display Concept

complete the action. The crew continues this process until all the procedures are completed. Feedback is presented visually on the procedures and status displays and may be presented by voice messages.

Multifunction Keyboard Concept

This concept uses a multifunction keyboard with programmable keys and a scratchpad representing an implementation in an aircraft that did not have display space for both the procedure and status displays, but did have a multifunction CDU. The scratchpad display presents the alert procedures. Aircraft status, system diagrams, and operational information are presented on the status display as in the other concepts. The multifunction keyboard provides the means to perform the control action by using the keys marked: "Go" to execute the active system item on the checklist (e.g., no smoking sign on); "Done" to indicate the completion of a pilot action (e.g., fuel balance check); and "Skip" to skip over an action item on the checklist.

The operation, as illustrated in Figure 12, shows that after line selecting the alert, the checklist appears on the scratchpad, and the actions are presented in sequence. To perform the action items, the pilot must depress the appropriate multifunction key. This procedure is continued until all items are completed. Feedback is provided on the scratchpad, and on the status display. The operation of the checklist on the scratchpad is the same as on the procedures display used in the other concepts.

Automatic Reconfiguration Concept

Any of the systems-aided concepts could incorporate pilot-initiated automatic system reconfiguration. For demonstration purposes, the multifunction keyboard concept was used to evaluate the feasibility of this control method. This concept requires the same steps to call up the checklist on the scratchpad display and the procedural steps on the keyboard. However, the crew has only to select one key, a dedicated key labeled EXECute, to initiate the corrective action. The system automatically does the action items that are interactive with the aircraft systems, at a predetermined rate, stopping at items that must be accomplished by the pilot. Action and status feedback are presented on the status and scratchpad displays (Figure 13). The crew has the option to stop the reconfiguration at any time.

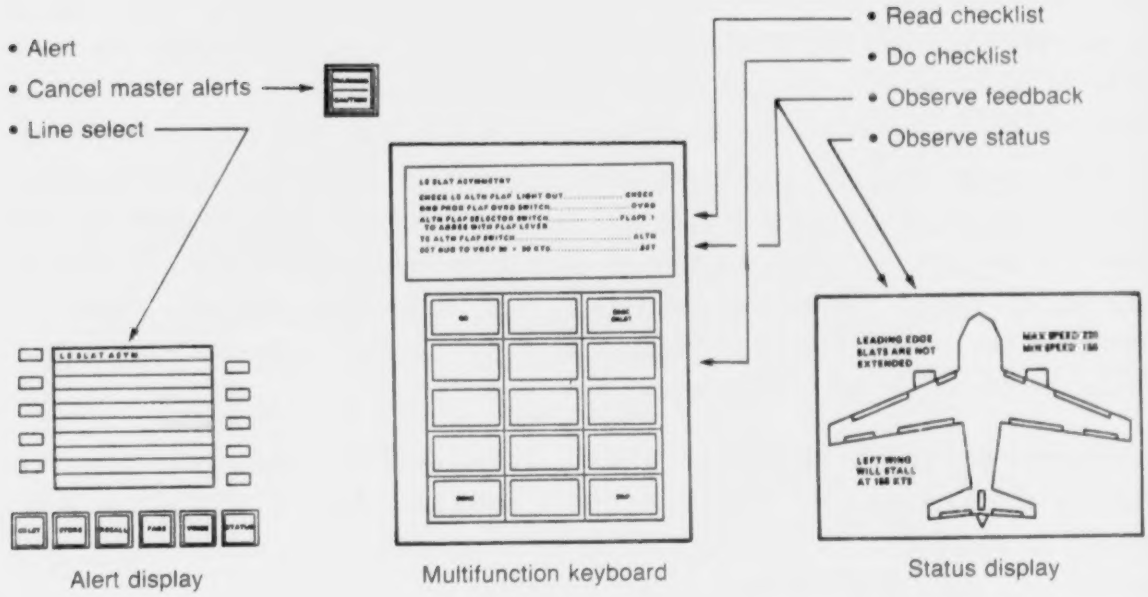

• Alert
• Cancel master alerts
• Line select
• Read checklist
• Do checklist
• Observe feedback
• Observe status
LE SLAT ASYM
LE SLAT ASYMMETRY
CHECK LE ALTN FLAP LIGHT OUT ..... CHECK
GND PROX FLAP OVRD SWITCH ..... OVRD
ALTN FLAP SELECTOR SWITCH TO AGREE WITH FLAP LEVER ..... FLAPS 1
TO ALTN FLAP SWITCH ..... ALTN
LEADING EDGE SLATS ARE NOT EXTENDED
LEFT WING WILL STALL
Alert display
Multifunction keyboard
Status display

Figure 12. The Multifunction Keyboard Concept

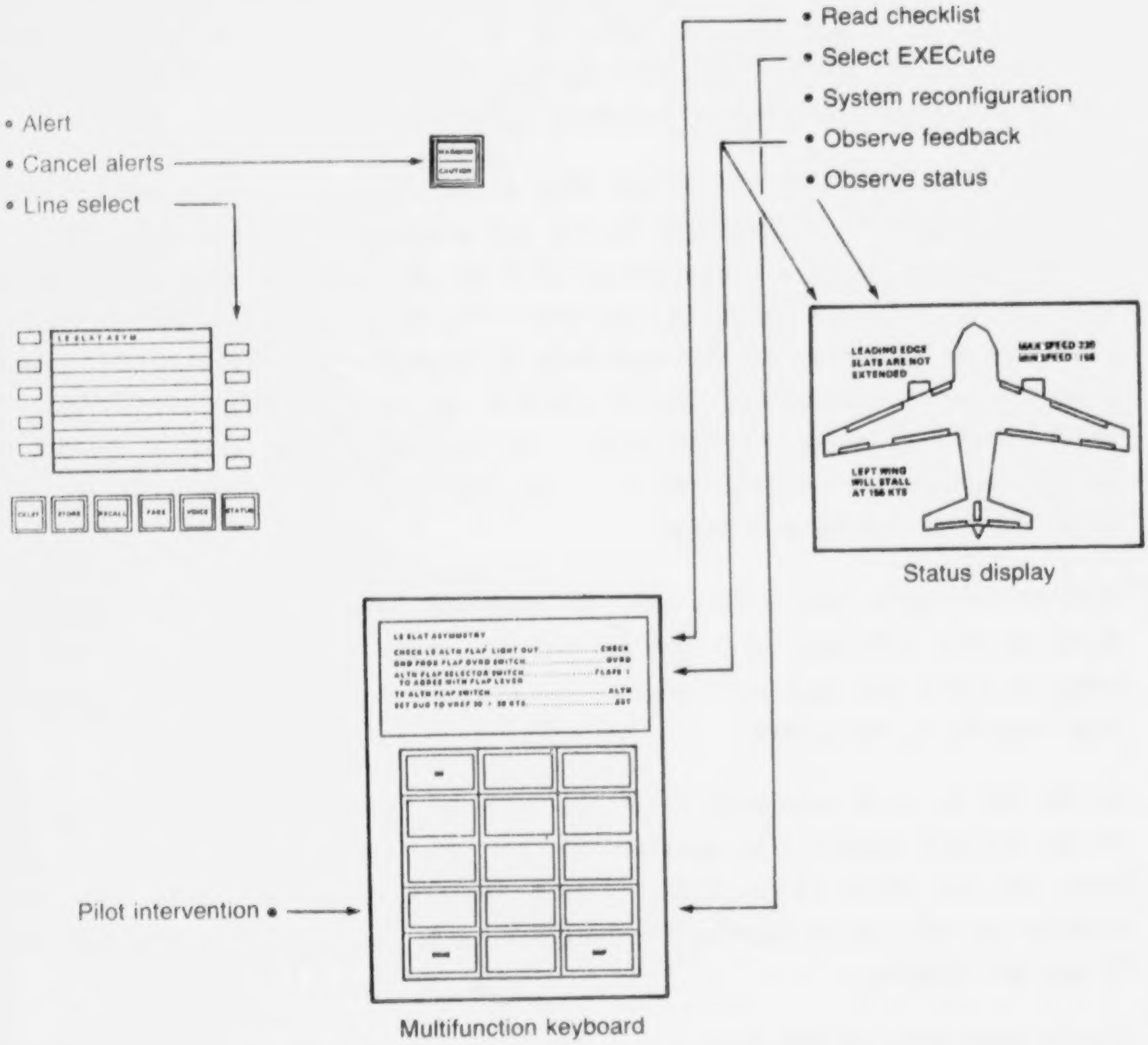

• Read checklist
• Select EXECute
• System reconfiguration
• Observe feedback
• Observe status
• Alert
• Cancel alerts
• Line select
WARNING
CAUTION
LE SLAT ASYM
CLEAR
STORE
RECALL
PAGE
VOICE
STATUS
LEADING EDGE SLATS ARE NOT EXTENDED
MAX SPEED 230
MIN SPEED 158
LEFT WING WILL STALL AT 156 KTS
Status display
LE SLAT ASYMMETRY
CHECK LE ALTN FLAP LIGHT OUT ... CHECK
GND PROX FLAP OVRD SWITCH ... OVRD
ALTN FLAP SELECTOR SWITCH TO AGREE WITH FLAP LEVER ... FLAPS 1
TE ALTN FLAP SWITCH ... ALTN
SET BUG TO VREF 30 + 50 KTS ... SET
Pilot intervention •
Multifunction keyboard

Figure 13. The Automatic Reconfiguration Concept

4.0 TEST PROCEDURE

The test period for each two-man crew will be approximately four hours. Upon arriving at the test location, you will be given a brief introduction to the simulator. The aircraft model you will fly is not intended to represent any plane with which you are familiar. It is a model of a wide bodied airplane with two engines and is being used solely to provide a flight task and should not be evaluated with respect to actual flight characteristics.

After the introduction, the pilots will be positioned at eye reference point in the simulator and permitted to fly the simulator for familiarization. A calibration of the eye view monitor will be performed so that eye tracking data can be obtained during all flights. Training for the first FSM concept will then be conducted for approximately 15 minutes. The training will emphasize the input procedures, system controls and display formats that will be utilized in performing the test tasks. An instructor pilot will be present to provide guidance throughout the training sessions. After the training session, the test trials will begin.

Each of the three test trials will be performed by crews of two pilots. The pilot in the left seat will operate the FSM while flying the aircraft. The pilot in the right seat will observe the FSM operation and evaluate the workload imposed by the system.

At the beginning of each test trial, you will be informed where you are in the flight (flight phase). In general, you will be instructed to respond to each alert as you would in an actual flight operations and to apply your best efforts not only in performing the response-task, but also in maintaining your flight performance.

At the completion of the test trials for each FSM concept, a debriefing questionnaire will be administered to elicit a subjective evaluation of the FSM operation and format and also so you can evaluate the amount of work required to use the control and displays. The test conductor and instructor pilot will be present during the debriefing to answer questions and ensure that the questionnaire is properly completed. At the completion of all test trials, you will be given another questionnaire which will permit you to make comparisons among all five FSM concepts and to provide suggestions for improvements. The test conductor will also perform and record an information interview in order to permit you to expand your opinion on any area you wish. Each pilot will also be asked to complete a standard questionnaire concerning prior flight experience.

APPENDIX C

POST-FLIGHT QUESTIONNAIRE

Crew____

Date_____________________ FSM Concept Flown__________________

Scenario____________________

Please complete the following questionnaire with respect to the alerts which occurred during your last flight. Use the "comments" space freely since your input is important in developing a viable system. Also, use the "comment" space to enumerate any operational difficulties encountered during the flight.

I. ALERTS AND PROCEDURES

1. Were all the alerts and expected pilot actions (procedure) clear and unambiguous?

   Yes _____ No _____

   If not, describe the alerts and the associated problem.

   ____

   ____

   ____

   ____

2a. Did the status display aid you in responding to the alert?

Yes ______ No ______

If it did, please describe how you used it and if it did not describe why you feel it didn't.

____

____

____

____

2b. Did the status display aid you in performing your flight task?

Yes ______ No ______

If it did, describe how you used it. If not describe why you feel it didn't.

____

____

____

____

3. Describe any problems you had with the test system during the flight.

____

____

____

____

II. WORKLOAD

If this was your first test flight, please give a brief description of the steps you use to respond to a non-normal situation on your current flight deck. It is not intended that you list the procedures for a specific alert, but rather the general steps, e.g., identify the problem; ascertain its severity; complete the memory items if there are any; etc.... If you have previously completed this description, skip to the next set of instructions.

____

____

____

____

Using your current procedure as a reference, answer the following questions, and compare the FSM concept which you have just flown to that reference.

1. Compared to your current alerting system, the attention-getting quality of the system you just flew was -

_____ Much better

_____ Moderately better

_____ Slightly better

_____ The same

_____ Slightly worse

_____ Moderately worse

_____ Much worse

Comments____

____

____

____

2. Compared to your current alerting system, the mental effort to understand what is wrong and what to do about it with the test system you just flew was -

_____ Much less

_____ Moderately less

_____ Slightly less

_____ The same

_____ Slight more

_____ Moderately more

_____ Much more

Comments____

____

____

____

3. Compared to your current response to alerting situations, the required responses with the test system you just flew were -

_____ Much easier

_____ Moderately easier

_____ Slightly easier

_____ The same

_____ Slightly harder

_____ Moderately harder

_____ Much harder

Comments____

____

____

____

4. Compared to your present response to alerting situations, the complexity of the responses with the test system you just flew were -

_____ Much lower

_____ Moderately lower

_____ Slight lower

_____ The same

_____ Slight higher

_____ Moderately higher

_____ Much higher

Comments____

____

____

____

5. Compared to your current operations, the ability to maintain other piloting functions while responding to alerts with the test system you just flew was -

_____ Much easier

_____ Moderately easier

_____ Slightly easier

_____ The same

_____ Slightly harder

_____ Moderately harder

_____ Much harder

Comments____

____

____

____

6. Compared to your current system, the overall workload you experienced operating the test system was:

_____ Much lower

_____ Moderately lower

_____ The same

_____ Moderately higher

_____ Much higher

Comments____

____

____

____

7. Compared to your current system, the probability of making an error with the test system was:

_____ Much less

_____ Moderately less

_____ The Same

_____ Moderately more

_____ Much more

Comments____

____

____

____

8. What design changes would you make in the test system you just flew?

____

____

____

____

APPENDIX D

FLIGHT STATUS MONITOR
PROGRAM DEBRIEFING QUESTIONNAIRE

PILOT QUESTIONNAIRE AND INSTRUCTIONS

Pilot Questionnaire

Note: This study is designed to assess the advantages and disadvantages of the Flight Status Monitor concept for possible use in commercial aviation. All information you give on this form will be kept confidential and will be summarized statistically with the data from other questionnaires.

Leave Blank
Subj. assigned code: ____________
Exp. No.: ____________
BOT: ____________
EOT: ____________
Vis. Tests: ____________
Form Compl. ____________

(Please Print all answers)

Name: ____

Address: ____

Phone (office pref.) (   ) ____________ Birthdate: ________________

Do you wear glasses/contacts while flying? yes no (circle)

If you have no military experience skip question 1a. - 1d.

==

1a. Military Background: Branch ____________________________

b. Did you receive military pilot training? yes no (circle)

c. List aircraft types in which you were qualified (if applicable - otherwise leave blank)

1st ______________ 2nd ______________

3rd ______________ 4th ______________

d. List all aviation-related (specialized) training: ______________

____

(continue on opposite side if necessary)

==

2.a Total hours flown (approx.) not including Flight Engr: __________ 2b. Years flying since solo: ________

3. Have you had any R&D experience as a member of a development project team for an advanced flight deck design?

______ Yes

______ No

If yes, please describe experience ________________________________

____

____

____

4. What is your current job (title and with whom)? ______________________

____

I. General

1. Rank the display control concepts according to your overall preference (1 = the concept you liked best and 5 = the concept you liked least)

	x	S.D.
Basic	3.1	1.5
Touch Panel	2.9	1.0
Voice	4.0	1.4
Multifunction CDU	2.7	1.2
Automatic Reconfiguration	2.3	1.3

II. Procedures Display

The purpose of this display is to provide the flight crew with step-by-step procedural information which will permit them to respond to non-normal situations. This display will have the capability of providing information that is currently presented in the Flight Manual and Operations Manual. The procedures display would also have the capability of presenting checklists for normal operations. Please answer the following questions concerning the display:

1. Compared to the operation of using the Quick Reference Handbook and Flight Manual or other on-board manuals for non-normal procedures, rate the effectiveness of using a procedures display to provide the handbook information.

_____ Current operation much better

9% Current operation somewhat better

_____ Both about the same

_____ Procedures Display somewhat better

91% Procedures Display much better

Comments ____

____

____

2. Check the situation in which the procedures display should be used.

9% All non-normal situations

9% Warning level alerts only

9% Warning and caution level alerts

73% All normal and non-normal procedures

_____ No use at all

3. What type of information should be presented on the procedures display? (Check all that apply)

100% Action items necessary to perform a procedure (e.g., LEFT ISOLATION VALVE ....OPEN

73% Pertinent information (not a specific action item) relevant to the situation and the conduct of the flight (e.g., WHEN STRUCTURAL DAMAGE SUSPECTED, AVOID HIGH IAS & ABRUPT MANEUVERING).

100% An indication that the action item has been completed (e.g., change action items, color, or size, or brightness

45% Other (specify) ______________________________

Comments ______________________________

4. Should the procedures display present procedural information only (dedicated), or could it be used to display other flight information (e.g., messages, flight profiles, etc.) when no procedures are present? (Check 1)

27% Dedicated

73% Multifunction

Comments ______________________________

5. How many procedural steps (action items) should be presented on the display at one time?

_____ One: current step only

_____ Three: current, past and next steps

_82%_ All actions for a procedure

_18%_ Other (please specify) ______________________________

____

Comments ______________________________

____

____

6. Which of the following formats do you prefer for action item presentation?

_____ PUMP 1 ON ---------- ON

_91%_ PUMP 1 ------------- ON

_____ TURN PUMP 1 -------- ON

_9%_ TURN PUMP 1 ON ----- ON

_____ OTHER ______________________________

Comments ______________________________

____

____

7. In general when should abbreviations be used in presenting the action items? (Check 1)

_9%_ Always

_____ Whenever an abbreviation is used on a particular display, it should be used throughout that particular display to be consistent

_27%_ Whenever an abbreviation is used on one display, it should be used on all displays to be consistent

_27%_ Only when needed to compress an action item into one line of the display

_____ Never

_36%_ Other (please specify) ______________________________

Comments ____

____

____

8. Referring to the first action item, "CHECK THE LE ALTN FLAP LIGHT OUT .... CHECK <". If more than one action item is displayed at one time, which indicator should be provided for the current action item?

_9%_ Symbol to the left of the action item (">", "*")

_____ Symbol to the right of the action item (">", "*")

_____ Symbol on both sides of the action item (">", "*")

_27%_ Color code the action item

_____ Brightness code the action item

_9%_ Flash the action item

_55%_ A combination of the above. specify ____________________

_____ No indication is required

_____ Other ____

Comments ____

____

____

9.a. How should the crew be provided feedback that an action item has been completed? (Rank the following methods from 1 to 7 with 1 being the most preferred and 7 being the least - mark an "x" beside the ranks for those methods you consider unacceptable)

5.4 Completed items removed from screen

1.3 Completed item different color

4.3 Completed item different size

3.3 Place a symbol (">" or "*", etc.) in front of completed items

4.1 Completed items indented two spaces

4.8 Message changes for completed item - e.g., PUMP 1.....ON to PUMP 1 ON

_____ Combination of above

7.9 Feedback not necessary

_____ Other (specify) ____________________

b. If changing color were used to indicate the completed items, which is more appropriate?

64% Green for completed items, white for incompleted ones

9% White for completed items, green for incompleted ones

27% ________ (fill in) for completed items ________ (fill in) for incomplete ones

Comments____________________

____

____

10a. If the procedure is too long to be presented on one page, how should multiple pages be indicated?

_____ Symbol at bottom left of each page (" ")

_____ Symbol at bottom right of each page (" ")

27% Page number at top right of each page ("2 of 4")

27% Page number at bottom right of each page ("2 of 4")

_____ Word at bottom left of each page ("CONTINUED", "MORE")

18% Word at bottom right of each page (e.g., "CONTINUE", "MORE"?

_____ Indication is not necessary

27% Other (please specify) ____

Comments ____

____

____

10b. If the procedure is too long to be presented on one page, should provisions be made to permit the crew to read and page through the checklist before taking any action?

32% Yes it is absolutely essential

45% It would be a benefit, but it is not necessary

18% No, it is not needed

Comments ____

____

____

11. Should voice messages be used to present action items? (e.g., "THROTTLE CLOSE" or "THROTTLE") Check as many as appropriate.

a. Voice messages should be presented:

_____ As the sole source of information

27% In combination with the visual display

18% Upon crew command by a dedicated switch

9% Automatically, after cancellation of the master caution and warning switch

_____ Automatically, after the completion of each action item

55% Never; voice messages should not be used to present action items

b. If voice messages are used, they should be:

_____ Repeated automatically at specified time intervals

70% Repeated upon crew request

30% Other (please specify) ______________________________

Comments ______________________________

____

____

12. Which of the following presentation formats should be used for voice messages?

_____ "TURN PUMP 2 OFF"

20% "PUMP 2 OFF"

_____ "PERFORM STEP"

60% The voice message should match the visual message whatever it is.

20% Other ______________________________

Comments ______________________________

____

____

13.a. How should the procedures display be called up? (Check as many as are appropriate.)

55% Automatically, when an alert first appears on the alerting alphanumeric display

27% Automatically, after cancellation of the master caution and warning switch

9% Automatically, for warning alert and manually for other alerts

9% Manually, by pressing a line select key on alerting display

_____ Manually, by pressing a line select key and then pressing the "PROCEDURES" OR "CHECKLIST" key on a dedicated keyboard

9% Other ______________________________

b. How should the crew interact with the procedures display? (i.e., initiate action item presentation, move to successive pages, and clear the display. This does not include performing the action items.)

9% By voice command

_____ By touching the display surface

73% By pressing dedicated keys adjacent to the action item

18% By using a separate keyboard

Comments ______________________________

____

____

14.a. If the crew is in the middle of a checklist for a caution or advisory-level alert, and another alert occurs, how should the incompleted checklist be handled? (Assume the new alert is the same alert level)

____ Remove and store the current checklist and display the new checklist

18% Display the current checklist until it is complete and then display the new one

9% Display both checklists with the current one at the top of the display and the new one on the bottom

____ Display both checklists with the current one on the bottom of the display and the new one on the top

73%C
91%W Have the new checklist integrated with the current checklist. The integrated checklist items would be rank-ordered by criticality.

____ Other (Specify)____________________

Comments ____________________

____

b. What would your response have been if the new alert was a warning-level alert? Mark the selected response with a "W".

15. Should the procedures display be cleared automatically after the last action has been performed, or should the crew be required to manually clear the display?

45% Automatically

55% Manually by crew

Comments ____________________

____

____

16. After an alert is signalled, and perhaps simultaneously with the display of procedures, there are a number of pieces of information that can be presented. Mark the following in the order you would like to see them (1 = the first information needed and 4 the last)

1.4 Aircraft status information (including operational limitations) which permit the crew to assess the situation with respect to flight control and airplane configuration.

2.1 System status information permitting the crew to evaluate the system that caused the alert and its potential effect on the flight.

2.8 Procedural status information providing the crew a graphic representation of the subsystem component which will be manipulated by the first action item on the procedures display.

_____ A combination of the above (please specify) ____________________

____

Comments ____

____

____

III. Status Displays

The purpose of the status display is to provide the crew with feedback concerning the present status of the flight and the aircraft and its systems. The information presented on this display encompasses a number of levels of information.

- Aircraft Status - Provides an indication of overall aircraft status including the operability of all control surfaces, engines, flight controls, landing gear, etc. In addition, alphanumeric information describing the impact of degraded system capability will be provided (i.e., operational limits, diversions, environmental constraints, policy, etc.)
- Failed System Status - provides a representation of the system that has produced the alert situation. The information presented about the system would include switch and valve position, operation parameters of the system (flows, temperature, pressures, etc.) and malfunctioning components.
- Procedural Status - as the procedural action items (checklist) are being performed, the crew may interact with various aircraft systems or system components. The procedural status display provides the crew a representation of the system or system component being addressed by the action item being worked.
- Information - the lowest information level of the status display and presents the supplementary information currently found in the handbook.

Please answer the following questions concerning the status display.

A. Aircraft Status Information

1. How important do you feel it is to provide the aircraft status information for alerts?

36% Necessary

64% Beneficial

____ Not needed

____ May have negative effect

____ Unacceptable

Comments ____

____

2. What information should be presented for aircraft status? (Check all that are appropriate.)

27% System faults (e.g., failed hydraulic pump or failed generator, etc.)

45% Operational status of the Comm/Nav. Equipment (i.e., radios, guidance equipment, etc.)

73% Operational status of landing gear, brakes, steering tires, etc.

82% Operational status of the engines

82% Operational status of flight control surfaces (i.e., flaps, slats, rudder, etc.)

82% Operational limits (i.e., speed limits, diversions, environmental constraint, policy, etc.)

Comments ____

____

____

3. Which mode(s) of presentation should be used to show aircraft status?

36% Written list (e.g., operational limits, diversions. etc.)

____ Pictorial outline of aircraft and pictorial representation of the systems

64% Combination of the above

____ Other ____

Comments ____

____

____

4. How should information be coded or formatted for aircraft status? (Check all that are appropriate)

55% System symbols or characters should be color coded according to alert urgency level generated by the failure condition

9% System symbols or characters should be brightness coded according to alert urgency level generated by the failure condition

27% System symbols or characters should be color coded according to operational status using colors other than those used for crew alerting (red and amber may not be used)

____ System, symbols or characters should be brightness coded according to operational status

36% Symbol, shape, or written messages should be used to indicate operational status

18% Quantitative information, (i.e., operational limits) should be presented in analog form (e.g., speed limit bars, flap limit drawing, etc.)

91% Quantitative information should be presented in digital form

____ Other ____

Comments ____

5. How and when should the aircraft status information be activated? (Check all that apply)

____ Automatically, at flight phase change

36% Automatically, when the alert occurs

27% Automatically, when the procedure display is activated

27% Automatically, at the completion of the fault procedure

45% Manually by pressing a switch

____ Manually by voice command

Comments ____

____

6. System Status Information (Failed-System and Procedures System Status)

1.a. How important is the failed-system status in assessing system/aircraft condition?

18% Absolutely necessary

64% Beneficial

9% Not needed

9% May have a negative effect

____ Totally unacceptable

b. How important is the procedural systems status display in performing the non-normal procedures for alerts?

9% Absolutely necessary

64% Beneficial

18% Not needed

9% May have a negative effect

____ Totally unacceptable

Comments ____

____

2. What should be presented as systems status? Mark all that are appropriate. (Use an "F" for those that are appropriate for failed-system status and a "P" for those appropriate for procedural status)

36% F Operational status of the system components, i.e., position
45% P of switches, state of pumps, etc.

35% F Quantitative parameters, i.e., temperatures, pressures,
27% P levels, flow rates, etc.

82% F
9% P Faulted components

45% F Trend information, i.e., near limiting condition and
18% P abnormal rates

_____ Other ____

Comments ____

____

____

3. Should the failed-system status provide greater levels of detail upon demand?

73% Yes

27% No

Comments ____

____

____

4. What type of presentation should be used for system status?

27% Written lists

45% Schematic diagrams

_____ Pictorial representative

27% Combination of the above. Specify ____________________

____

Comments ____

____

____

5. How should the system status information be coded or formatted? (Check all that are appropriate.)

73% Symbol or character color coded according to alert urgency level generated by the failure condition

18% Symbol or character brightness code according to alert urgency level generated by the failure condition

45% Symbol or character color coded according to operational status using colors other than those used for crew alerting (e.g., red and amber may not be used)

_____ Symbol or character brightness coded according to operational status

9% Symbol, shape, or written message which change according to operational level

_____ Quantitative information displayed on an analog scale (e.g., speed limit bars, flap limit drawing, etc.)

82% Quantitative information displayed digitally

_____ Other ______________________________

Comments ______________________________

____

____

6. How should the crew interact with the Status Display (e.g., system selection, paging, and erasing)?

55% Dedicated switch(s) on the display-control panel

27% Multifunction switch(s) on a multifunction control panel

9% A touch panel overlay on the status display

9% Voice command

Comments ____

____

____

7. What effect did the status display have on your response to the alerting situation?

____

____

____

____

IV. System Controls

The following questions concern the method the crew uses to interact with the Flight Status Monitor.

1. Rank order each concept of performing the action item according to each of the following criteria. Place a "1" next to the most preferred concept and "5" next to the least acceptable concept for each criteria.

Concept	Ease of Use	Probability of Error	Ease of Training	Overall Operability	Overall Desirability
Dedicated System Panel					
Multifunction Keyboard					
Touch Panel					
Voice Command					
Automatic Reconfiguration					

Comments

2. For a touch panel interactive system, which do you prefer?

18% Touch area on the procedures display next to the procedural action items without a status display

9% Touch area on the procedures display next to the procedural action items with a status display

64% Touch area over the component symbol on status display, i.e., you touch the component you wish to change with a procedures display

____ Action items appearing on the status display which has the touch area over the components symbols without a procedures display

____ Other

Comments

. If subsystem/system panels can be displayed and operated via touch interactive displays, would dedicated aircraft subsystem control panels still be required? (Assume that sufficient redundancy is provided to ensure system reliability)

45% Yes

55% No

Comments ____

____

____

4a. Should voice be used to control the FSM?

_____ Yes, it is a necessary component

45% It would be a benefit, but is not necessary

55% It should not be used

_____ Other ____

Comments ____

____

____

4b. If voice control is used, which of the following configurations do you prefer?

_____ Voice control only

18% Voice in combination with a dedicated systems panel

45% Voice in combination with a multifunction keyboard

27% Voice in combination with a touch panel

_____ Other ____

Comments ____

____

____

5. For which FSM function(s) should voice control be used? (Check all that apply)

64% Calling up the procedures display

73% Calling up the status display

18% Cancelling the masters alerts

27% Selecting alerts for which you want a display of procedures/status

27% Storing, recalling alerts

55% Performing procedural action items

18% Other

Comments

6. How should voice control be activaced?

18% Dedicated or multifunction switch on a display-control panel

Knee switch

27% Mike switch

9% Voice command (using a code word)

9% Always be active during operation

36% Other

Comments

7. If multilegend keys are used on a multifunction keyboard for performing procedures, what should be presented on the legends?

_____ Procedure step number

82% Procedure action item

18% Identification of system component requiring reconfiguration

_____ Other ____

Comments ____

____

____

8. If an automatic reconfiguration system is used, which of the following features should be incorporated? (Check all that apply)

73% Capability should be crew selectable

27% Crew should have capability to see previous configuration (After automatic reconfiguration completed)

73% System status should be provided after reconfiguration

100% Automatic sequence should stop short of critical action item, (e.g., engine shut down, gear up/down)

82% Crew should have the capability to stop the automatic sequence

_____ Other ____

Comments ____

____

____

9. If you had the responsibility for developing an FSM, which controls and displays would you implement to provide crew guidance and status information?

Controls ____

____

____

Displays ____

____

____

V. Suggested Changes

Review each of the FSM display/control concepts and indicate any suggestions you may have for changing the concept to make it more appropriate?

Basic Concept

Touch Panel

Voice

Multifunction CDU

Automatic Reconfiguration

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